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AN INTRODUCTION TO BIOLOGY

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AN INTRODUCTION TO BIOLOGY

CHAPTER I

FUNDAMENTALS

SHORTLY after the tragic war commenced in 1914, a German writer, Bernhardi, startled the newspaper-reading public with the statement that war was a biological necessity. People began to ask what a "biological necessity" was, anyway, and what was "biology." Other events in the war brought the word still more in the public eye until now it has become part of the stock-in-trade of the novelist. The public body is beginning to feel that biological discoveries may result in more disturbing effects than those of the chemist and engineer.

Biology, as we shall use the term, means the study of living creatures—living organisms is a better way to put it. It is the science that deals with that intangible phenomenon—life.

Modern biology (essentially arising in the nineteenth century) grew out of the studies which we still call *Natural History,* and which were initiated many, many centuries ago, indeed, by primitive man, who was vastly concerned with his food supplies and his competitors in the jungle. History is vague about those who first produced our domesticated animals, and little is known of the biological observations and discoveries of the ancient civilisations of the East, which perished amidst the ruins of their empires.

We have to look to Aristotle (384 B.C.-322 B.C.) for the founding of the Science of Natural History, and for the first great effort at a classification of animals, with observations on their habits and structure. The study so ably founded declined to a much lower level, and then came that long barren period of the Middle Ages. A thousand years and more after the Greeks had made a fair beginning in the quest of things alive, a fresh start was made by Vesalius, a Belgian, whose work, however, was more closely associated with the University of Padua in Italy, where from 1537, as Doctor of Medicine, he lectured on Anatomy and Surgery. Vesalius' great work was anatomical, the study of the structure of the human body, but at the same period the study of the functions of the parts of the human body received its great impulse through the discovery of the circulation of the blood by an Englishman, William Harvey. After his early studies, Harvey also left the country of his birth and went to Padua to study medicine under the great master, Vesalius. His discoveries were published after his return to England, when he became Physician to St. Bartholomew's Hospital in 1609 and Physician to King Charles I. Thus Anatomy, the study of structure, and Physiology, the science which attempts to answer the question, "What is happening in the structure when it is alive?" commenced their great period of development. For many years after this the study of function remained closely linked with human anatomy and medicine.

As the years passed on a succession of pioneers penetrated more and more deeply into the mystery of living things. Animals and plants were collected, described and named, and their anatomy was studied in detail until the most minute structures came to be investigated. Quite early in the seventeenth century the microscope, newly invented, was applied to the study of plant and animal structure. This was

the beginning of a new era. The vast world of minute living organisms (invisible to the naked eye, but so important to-day in disease and economics) was gradually revealed. Amongst the first of these discoveries the pictures of the cellular structure of plants by Hooke, Grew and Malpighi are of the greatest interest, for they foreshadowed the cell theories of the nineteenth century and the fundamentals of modern biology. So with the parallel development of studies in anatomy (gross and minute), classification of animals and plants, and studies of function, we are brought to the end of the eighteenth century. Linnæus had produced his great catalogue of animals and plants and established the system of naming living organisms which we use to-day. The discovery of oxygen in 1774 by Priestley was destined to exert a profound influence upon the advance of physiology; it was impossible to understand the real meaning of respiration before then. Also, thanks to the remarkable advance in studies of comparative anatomy, the belief in a theory of evolution, several times suggested in a nebulous way by earlier philosophers, was assuming definite shape. (Erasmus Darwin, 1731-1802, grandfather of Charles Darwin, Buffon, 1707-1788, and very especially Lamarck, whose theory still holds the field with that of Darwin, are names to be noted.)

The nineteenth century brought the discovery of an identity of structure between animals and plants, the discovery of the cell as the unit of structure. Intimately connected with this was the discovery of *Protoplasm,* the semifluid substance of the cell which is endowed with the qualities of life—the real living substance. The name was given in 1840 to the living substance of plants. It had been observed in 1835 in animals and called *Sarcode.* In 1861 it was definitely shown that sarcode and protoplasm were identical. The general acceptance amongst scientists of the

theory of evolution, due largely to the work of Charles Darwin, provided the complete key to the position thus gained, for the evidence indicated that not only had animal life as we know it evolved—*i.e.*, originated—by descent from lower and more simple types, but that both animals and plants had had a common ancestry. The fundamental phenomena of life are, in fact, the same in animals and plants.

What gravitation has been to the astronomer the concept of evolution has been to the biologist. The knowledge that there has been a continuous stream of life down the ages, so that the animal and plant worlds resemble a giant genealogical tree with ever multiplying ramifications and divergencies, a tree which has taken millions of years for its unfolding, has entirely altered our viewpoint and methods of research. If we cannot study the function of the thyroid gland in man, we may be able to do it in one of the lower animals. A realisation that the same essential units of structure are present in plants as in animals suggests that a study of certain growth abnormalities in plants should be of interest to one searching for the cause of cancer. The knowledge that the mechanism of reproduction and heredity is essentially the same throughout the world of living things indicates that we may discover facts of the greatest importance to man by investigating the inheritance of the characters of a small fly. With such an example we can work through many generations in a year, an impossible thing with the slow-breeding higher animals.

So the field has widened, and, with increasing interest and the realisation of the direct value of biological study, more and more workers have been attracted to the field. The microscope has been developed to a power hitherto undreamt of, new technique and remarkable instruments and experiments have been invented and devised, and from purely

descriptive natural history we have reached a stage in which man is beginning to learn something of the "mechanism" of life and the possibility of controlling it.

It is now desirable that we should turn to that unit of structure, the *Cell,* which is of such great importance in modern biology. The cell theory of animal and plant structure was not launched until 1838, the year in which two friends, Schleiden, a botanist, and Schwann, an anatomist, compared notes and commenced to collaborate, yet these tiny units of living matter had been seen and depicted 175 years before, when Hooke examined a thin section of cork, and Malpighi and Grew applied the microscope to thin sections of plant stems. Even Schleiden and Schwann did not realise at first the true nature of cells. That is why the term "cell" is a misnomer in biology. We commonly think of cells as little chambers, and that is how they appeared to the early workers with the microscope. They attached too much importance to the cell wall. Gradually it came to be realised that the essential part of the cell was the living substance, protoplasm; a cell wall might or might not be differentiated. The name "cell" has, however, become a fixture. Instead, therefore, of a hollow chamber, we regard a cell as a small, usually microscopic, mass of protoplasm, generally containing a smaller body of modified protoplasm called the nucleus, and possibly enclosed in a membrane, the cell wall. All living things are composed of cells and their products, but the numbers of these units present, their diversity and specialisation, vary enormously. At one end of the scale there are microscopic creatures consisting of only a single cell; at the other end we have the highly complex multicellular animals containing millions and millions of cells specialised in form and function—*e.g.*, muscle cells, nerve cells, bone cells, gland cells, and

so on. A generalised cell is illustrated in Fig. 1, and there are also shown the germ cells of a multicellular animal. On the whole, the student new to biology is probably more startled when he first sees under the microscope a living creature consisting of a single cell (like the famous amœba depicted in the figure) than when he studies the frog or man. Those who have seen the minute particle of semifluid sub-

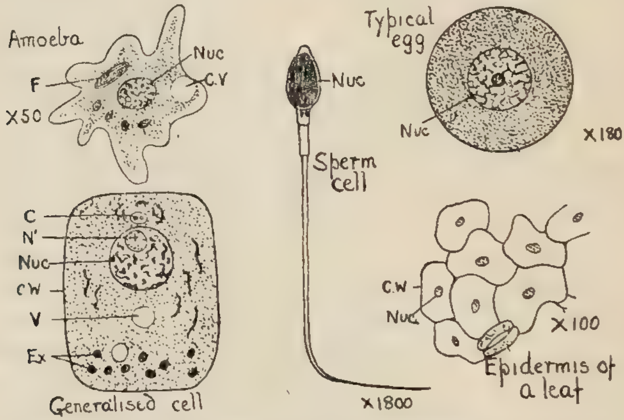

Fig 1. Cells, highly magnified.
C. Centrosomes. C.V. Contractile Vacuole. C.W. Cell Wall. Ex. Products of cell life F Food particle. N. Nucleolus. Nuc. Nucleus. V. Vacuole.

stance which is an amœba, move about, capture food, digest it, respond to changes in its environment, and reproduce its kind, will understand that feeling. The cell substance, protoplasm, is the essence of life. It is this which is in some way different from all that is non-living. To discover its structure and composition, its response to stimuli, and its behaviour under varying conditions are fundamental efforts in biology. Yet protoplasm still holds its great secret.

Very simple microscopic investigation enables us to distinguish between nucleus and surrounding protoplasm. The protoplasm of the nucleus contains certain different chemical substances, and its presence

appears in most cases essential for the well-being of the cell. Thus it has been possible to cut a single-celled creature in two so that one part contains the entire nucleus. That part continues to live, the other soon dies. A human being (almost any other animal or plant might be taken as an example) arises from the product of two tiny germ cells (Fig. 1). These two cells must have contained factors for all the characters inherited from their parents. There is considerable evidence to show that the mechanism for this is situated in the nucleus. Obviously, the complexity of the nucleus must be far greater than is visible with the highest powers of the microscope. A glimpse, however, of this complexity is seen when a cell divides.

The cell is the unit of structure; it is also a unit of function, for all the activities which are characteristic of life take place within the cell.

The simplest living creatures are microscopic and consist of one single cell; in this group of organisms it is very difficult to distinguish between plants and animals. Of course, this age-old grouping of living creatures was based upon the evident differences between the higher plants and animals. An oak-tree is clearly very different from a tiger. The differences fade away amidst the unicellular forms of life, and this is what one would expect if plants and animals had had a common ancestry. The bacteria, which are the most minute of all organisms (and so well known as mere names to the everyday world), can scarcely be said to be plants or animals; the distinction simply has not arisen. Now if we observe a member of this unicellular group, such as *Amœba** we see that it can move about, its protoplasm appears to be able

* Common in ditches and ponds, present in the soil, and with relatives parasitic within the bodies of other animals, including man.

to discriminate between substances it accidentally touches, it flows round and captures food particles which it can digest, it is sensitive and responds to changes in its environment, it grows, and having reached a certain size it reproduces by dividing into two or more little amœbæ. Special tests would show that it breathes and also that it excretes waste matter. It presents, in short, all those fundamentals which enable us to say that here we have a live thing, although at the same time we find it impossible to define life. These fundamentals, few in number, are universal amongst the infinite multitude of different sorts of living creatures. Structures may vary to an extraordinary degree, but evidently the activities which they perform are everywhere much the same.

The amazing substance, *Protoplasm,* appears to be composed of only a small number of chemical elements. It is, however, neither a chemical compound nor a simple mixture of such. Rather would it appear to be a complex of systems—an organised structure. We find present a large percentage of water (75 per cent.), and various chemical substances of which three classes, proteins, carbohydrates, and fats, predominate, together with certain mineral salts. The reader nonversed in chemical lore knows what fats are like, and he probably knows that they are compounds of carbon, hydrogen, and oxygen. He cannot help but be familiar with some carbohydrates—sugars, starch, cellulose (also compounds of carbon, hydrogen, and oxygen). The proteins, on the other hand, are less familiar, but they are the fundamental substances responsible for the phenomena known as life. They consist of carbon, hydrogen, oxygen, nitrogen, and usually sulphur or phosphorus, or both. Whilst proteins are built up of a few elements, these are combined in such elaborate structures that countless varieties may exist. It is now pretty clear that protoplasm could not exist except for proteins.

There seems no end to the number of possible compounds of carbon, hydrogen, and oxygen (with or without other elements). This is all due to carbon atom linking to carbon atom until very big molecules result. But this is not all. There are two tartaric acids known, although each has the same number and kinds of atoms in its molecule. The possibility of this is due to the fact that the atoms may be arranged in the tartaric acid molecule in two different ways so that the two different acids bear the same relation to one another as one's right hand to the left, or a reflection in a mirror to the thing itself. Come now to the proteins. Instead of three or four atoms in the molecule we may find thousands. On top of this there is the same kind of possibility of difference in internal arrangement of atoms—in this case, however, not two possibilities, but hundreds of thousands. And so we have the explanation of the fact that whilst the red colouring substance of the blood in *all* the different vertebrates is *Hæmoglobin,* yet there is one hæmoglobin in human blood, another in the horse, another in the pig, and so on, and so on.

Now imagine that living protoplasm is not even a mixture of such proteins, but an elaborate structure in which they play the fundamental part, and you will realise the difficulties in the discovery of the phenomena of life.

What goes on, then, in a small mass of living protoplasm, such as a single cell? It is unstable, with physical and chemical processes constantly taking place. It is this constant change which is the characteristic of life, and to the sum total of it all we apply the term *Metabolism*. But metabolism is not independent of the environment. One result of the activity going on is that the protoplasm increases in amount; it grows. Material is required from without to supply the demands of growth and also to

make up for the substances which have broken down and given up their store of energy. Waste substances which have been formed must be removed. So with life goes concurrently the need of food (nutrition) and the removal of waste (excretion). All the activities which living creatures exhibit demand supplies of energy. In by far the greater number of cases, though not in all, energy is ultimately set free by processes of oxidation. For this purpose living protoplasm requires supplies of oxygen, and we use the term *Respiration* for the intake and use of this substance and the complementary passage out of certain products which result.

It is practically impossible for living protoplasm to find materials which without change it can attach to its own complicated and very special structure. It has, however, the power of bringing its food into a form which can be utilised. Green plant cells can do much more in this way than animal cells, and herein we are provided with one of the distinguishing characters of the two great groups of living things. It is typical of plants that they can build up fats, carbohydrates and proteins from very simple substances like water, carbon dioxide, nitrates, etc. Animals require their foodstuffs already in the form of complex organic compounds. This remarkable faculty of plants depends upon the presence of the green substance, chlorophyll, and the energy of sunlight. Without plants and photosynthesis it is not possible to conceive of the existence of the animal world as we see it to-day.

If we lower the temperature of the environment we slow down the chemical changes which are inseparable from living protoplasm. This is exhibited by the retardation of plant growth at low temperature. Animals whose temperature is the same as the environment tend to become sluggish, and many fall into a kind of sleep. If the lowering of temperature

merely stopped the chemical actions without destroying any structure, there would be no reason why, after being frozen for some time, protoplasm should not take up its activity again. This is often the case, and it is borne out by the fact that it is possible to expose bacteria to a temperature of liquid air without preventing them from continuing their life activity after an elevation of temperature.

Why, then, cannot most animals withstand freezing? The answer is that since protoplasm contains a large percentage of water, the freezing of this and the formation of ice crystals shatters the complex structure which is so special a feature of protoplasm, or withdraws the water. Nothing could show more simply that living protoplasm is more than a collection of certain chemical substances. Higher animals with a more complex physiology cannot stand exposure to cold for other reasons, and for the human being a drop in the temperature of the body from 37·5° to 27° C. means very severe damage.

The optimum and the maximum temperature varies considerably for the protoplasm of different living things, but there are very few animals which will withstand a temperature of 45-50° C. Striking exceptions are the few animals and plants which have become adapted to life in hot springs.

We have not defined life, but we can usually recognise it. Sometimes, however, this is a matter of difficulty, and one is faced with such puzzles as that of any ordinary seed in the dry state or even of a hibernating hedgehog. The usual manifestations of life are absent. We cannot say they are dead; we can speak of them as lifeless. It has been ably said that they are like a clock which has been wound up but requires a touch on the pendulum to set it going. Using the same analogy, a dead creature might be compared to a broken clock.

CHAPTER II

THE FEEDING OF ANIMALS AND PLANTS AND THE CHEMICAL PHENOMENA INVOLVED

It has been said that all the activities of animal life may be resolved into the consequences of two potent driving forces—the fulfilment of the urge for food and for reproduction. Certain it is that nothing could be more interesting than the diversity of methods exhibited by living organisms for the acquirement of food and the processes whereby this is utilised.

It is practically only since the war that one has really appreciated the fact that " Man cannot live by bread alone "; bread is not sufficient to supply a human being (or, for that matter, a bird or mammal) with an adequate quantity of what we regard as food substances. Something else is involved. At present it is thought to be small quantities of somewhat problematic substances known as *Vitamins*. The empirical knowledge of our ancestors of the efficiency of fruit in the prevention of scurvy, and of cod-liver oil in rickets, has in the past ten years come into its own.

Manifestly it would be both impossible as well as undesirable to give a catalogue of animal and plant feeding methods in these pages. Instead we shall tackle the more fundamental problems of how non-living foreign stuffs are brought into the complex system of living protoplasm.

It is, perhaps, excusable if for a second we theorise on the probable method of nutrition characteristic of the first and most simple forms of life. To-day there

are three modes of nutrition (with possible combinations) met with in nature, and these are:

1. *Holophytic.*—The utilisation of simple aqueous and gaseous inorganic substances so characteristic of the green plants, and the phenomenon of *Photosynthesis* by which these simple substances are built up into fats, carbohydrates, and proteins.

2. *Holozoic.*—The typical animal type of nutrition—the intake of particles of solid food consisting of proteins, fats, and carbohydrates which are, or have been, parts of other animals and plants.

3. *Saprophytic.*—The absorption of organic substances in fluid form. Characteristic of a few animals and of plants without chlorophyll—*e.g.*, fungi (mushrooms and mildews)—and bacteria.

Probably *Saprophytic* nutrition is the most ancient and simplest type. Bacteria feed solely in this manner to-day. The higher animals are all dependent directly or indirectly on the green plants. Possibly, therefore, the evolution of the remarkable mechanism of photosynthesis came next, and holozoic feeding last.

It was originally believed that plants obtained all their food supplies from the soil by means of the roots, and it was not until the beginning of the nineteenth century (1800-1845) that it was completely realised that the air is actually the source of all the carbon of green plants. The chlorophyll of plants, which gives the dominant character to the land areas of the earth's surface, is an essential factor in the process. It is not remarkable that "chlorophyll" has been termed the most wonderful pigment substance in the world; without it there would be no animal life as we know it to-day.

Chlorophyll is found in the plant cells in little bodies which lie in the protoplasm outside the nucleus. As a matter of fact, the name is somewhat loosely applied to four different coloured substances: Chloro-

phyll A, Chlorophyll B, Carobin (red), and Xanthophyll (yellow).

In the presence of light the chloroplastids convert carbon dioxide (which is absorbed by the leaves from the air) and water (absorbed from the soil) into carbohydrates. The phenomenon is known as photosynthesis. It is not difficult to demonstrate the end results, and they may be summed up in the equation

$$\underbrace{6CO_2}_{\text{carbon dioxide}} + \underbrace{6H_2O}_{\text{water}} = \underbrace{C_6H_{12}O_6}_{\text{sugar}} + \underbrace{6O_2}_{\text{oxygen.}}$$

The exact steps in this synthesis, so important to the continuation of life on the earth, have so far eluded man's efforts of discovery. Theories there are, of course, without number. The schoolgirl is often told of the process as if all were known, the favourite explanation being that carbon dioxide and water are combined to give formaldehyde, and that this is changed into sugar. The truth is there is no more evidence for believing that formaldehyde is the first stage than there is to support other theories.

Only a short time ago there was no evidence that carbon dioxide and water could be made to combine in the chemical laboratory without an expenditure of energy that was quite incomparable with what goes on in plants. If the discoveries of Professor Baly and his co-workers at Liverpool, published recently, turn out to be correct, quite another aspect of the matter must be faced. Baly and his colleagues believe that they have synthesised carbohydrates directly from carbon dioxide as the result of exposing water through which carbon dioxide is bubbled to *visible* light. The water contained a suspension of a powder (cobalt carbonate). The theory is that the carbon dioxide becomes concentrated (more correctly, adsorbed) on the surfaces of the suspended particles, and then is photosynthesised to carbohydrate.

It is stated that the total yield of carbohydrate is quite comparable with that produced in plants. Probably there is still a long way to go before the full explanation of the photosynthesis of carbohydrates and the manufacture of proteins in plant leaves is understood.

Our short study of animal nutrition will be confined chiefly to our present knowledge of how the food substances become incorporated into the animal body. Since animal foods are in a far more concentrated form than the simple substances absorbed by plants, there is no need for an extensive outer absorbing surface, and so, instead of leaves and roots, we usually find an internal cavity, or tube, into which food is taken, and where it can suitably be treated. The passage of food into this alimentary canal is not really passage of food into the animal body, and it is possible and frequent that substances entering this food space pass through it, or are thrown out the way they came in, without ever having entered a single living cell.

It is often thought that the processes of *Digestion* which go on in the alimentary canals of animals are chemical processes involved solely in making soluble the substances taken in, so that the products may easily pass through the cells lining the canal (the stomach and intestine in man) and eventually reach all parts of the body. The matter is not nearly so simple. The living protoplasm will only "accept" certain combinations. We may eat protein, say, in the form of mutton or fish, but the proteins of sheep muscle or fish muscle are not the same as those of human protoplasm. It is not sufficient, therefore, that these proteins be brought into soluble form. They must be converted into substances which can be built up by the human protoplasm into its own proteins. The same applies to the carbohydrates. Starch is insoluble in water and cannot pass through the cell walls into the protoplasm; it cannot, therefore, pass through the alimentary canal

walls in this form. It must be converted into something else. It is changed by digestive juices into sugar. But it must be a sugar that can be utilised. Bearing this in mind, it is possible to modify an old adage to read: "What is one animal's meat is another animal's poison."

Restriction to some particular type of diet is best seen, perhaps, amongst the insects, where one species is often associated with one particular type of plant. Remove the latter, and the insect disappears. Other remarkable examples are the clothes moths obtaining everything from a diet of wool, and the white ants constructing all their organs on a diet of dried wood. A less specialised form of restriction is that of carnivorous and herbivorous animals. Sheep would find a diet of meat impossible, and a tiger would soon look very sick if provided with meals of grass!

In many of these cases, however, the inability to utilise other food sources is a question of structure rather than, or as well as, chemistry. Thus, herbivorous animals have much longer food canals than carnivorous creatures. A tiger's teeth are specially adapted for killing and tearing its prey, a sheep's dentition is peculiarly modified for the purpose of grinding up grass. One dentition could not do the work of the other.

It is, perhaps, more surprising to find how diverse the foodstuffs of an animal can be rather than to find the restrictions. The chief foods fall into only three classes—Proteins, Carbohydrates, and Fats—and the mechanism of digestion is such that the means provided to digest one protein are usually capable of digesting a host of members of this class; the same thing applies to the fats and carbohydrates.

Digestion is brought about by the addition to the food of certain chemical substances known as *enzymes*. The chemical composition of these substances is still unknown. They are certainly remarkable, and if their

recognition is a matter of modern times (since 1896), their activities have been known and blessed for thousands of years, since both the leavening of bread and the conversion of grape-juice into wine is the result of an enzyme produced by living yeast cells (yeast is a unicellular organism usually regarded as a plant).

The extraordinary thing is that the type of operation involved in all the digestive processes is the same, although the substances digested are so diverse. The operation may be illustrated by taking the case of the proteins. Chemical analysis has shown that the proteins are built up of molecules of amino-acids linked together. Enzymes which digest proteins break this linkage by the addition of a molecule of water. But the enzyme neither supplies the water *nor is itself used up in the process*. Although the action of an enzyme is, of course, absolutely different, it will serve as an analogy if we compare its influence to that of lubricating oil in an engine. The latter enables an action to go at greater speed, and although some of it may be destroyed, the necessity for continual oiling is generally due to simple loss by leakage.

We have explained that, with the addition of water, proteins split up into constituent amino-acids. The process is known as *Hydrolysis*. The digestion of carbohydrates and fats is also a process of hydrolysis.

Finally, after absorption of amino-acids, sugars, or the products of fat digestion into the living cells, it is enzyme activity again which results in the opposite process to digestion—*i.e.*, the rebuilding into the substances of the organism.

These digestive processes are accompanied by an infinite series of other interesting features. The enzymes may not be produced in the active condition, otherwise they might act on and destroy one another (there are three, for example, in pancreatic juice). They may need to come into contact at the proper

place and time with something else which sets them off. Thus trypsin in the pancreatic juice of man is inactive until it reaches the intestine. Again, the pepsin of the stomach may successfully attack some of our very tough restaurant steak, yet it does not digest the walls of the stomach, because the walls produce an anti-pepsin which hinders such action. A tapeworm may live in the human intestine where all sorts of substances are being dissolved. It survives because it actually produces anti-ferments which antagonise the action of the digestive juices.

Since proteins are essential for the growth as well as the repair of waste of protoplasm, they are essential in all animal foods. Proteins alone will supply all needs—energy as well as repair substances. The limit, therefore, of diet restriction in animals would be some protein containing substance. Carbohydrates and fats are more economical for the production of energy, and so one usually finds a varying mixture of these with the proteins. The need for water and salts must be remembered, since 75 per cent. or more of an animal's body may be water.

Now we are brought to a curious problem. Recent practice has shown that in the case of man and also of his domestic animals a sufficiency of actual food substance may be present, and yet disorder may result which can be traced to the nutrition. The condition to which we are referring is not due to the presence of something deleterious in the food; it seems rather to be due to an absence. It was first noticed when scurvy was common on board ships in the days when diet was more restricted and fresh vegetables were missing. The food was not appetising, but the real cause of scurvy (found out many years later) was the deficiency of very small quantities of a substance present in fruit and vegetables. A small quantity of orange juice could, in fact, put matters right. Lime juice, since it can be stored for some time without loss of the

precious substance, thus came into ship use. Such accessory food substances have been called *Vitamins*, and, since very little is yet known of their composition, they have been labelled in a very general way. The one to which we refer above (anti-scorbutic vitamin) is called *Water Soluble C*.

Another disease clearly associated with a nutritional deficiency is beri-beri. This is prevalent amongst Eastern peoples, and is thus met with in some of our own Eastern colonies. After being a puzzle for a long time, it was eventually discovered to be due to a restriction of diet to white rice (polished rice as we know it—*i.e.*, without the husk). If unpolished rice is eaten, the disease does not arise, although most of us who relish the delicacies of a modern dinner would probably say that this was restriction enough in all conscience. The disease can easily be imitated in domestic fowls by feeding them exclusively on polished rice; a peculiar degeneration of the nerves results. The trouble, even when serious, can be cured *by the addition of rice bran*, or of other foods which are known to contain the missing substance, which is called *Water Soluble B*.

From the time of the recent discovery of the vitamins up to two years ago only one other vitamin was recognised. It was called *Fat Soluble A*, because it was generally found associated with the fats of natural foods, and two functions were linked with it. Thus, if laboratory-bred rats or young puppies are fed upon a complete food supply (complete, that is, from the point of view of quantity of proteins, fats, carbohydrates, and salts), which has, however, been chemically treated so that all the fat soluble vitamin A has been removed, growth does not take place and the calcification of the bones is deficient. The latter disease is *Rickets*. The addition of an extremely small quantity of fresh milk, cod-liver oil, or fresh butter corrects the deficiency.

Very recently indeed vitamin A has been shown to be a mixture of three vitamins, and we now have A, which is necessary for growth; D, the absence of which causes rickets; and E, which appears to be necessary in order that Reproduction may take place.

The extraordinary importance of these discoveries to the welfare of man must be obvious at once. Vitamins appear to be very delicate substances; they are easily destroyed and are associated intimately with fresh food substances. Thus, cooking, tinning, and all sorts of treatments so common to-day result in their loss. Many foods, like margarine and preserved milk, may be quite suitable if the deficiency is recognised and made up by the addition of small quantities of substances containing vitamins.

So much on the subject of food. Now a few words on food capture and the inter-relationships of plants and animals. It has been well said that life is summed up in the conjugation of the French verb *manger*—the pleasant active voice (except for the dyspeptic!) and its awful alternative, the passive. In general the total population of any region of the earth is a direct reflection of the balance between *je mange,* etc., and *je suis mangé,* etc.

The green plants must be the ultimate link in the food chain, seeing that they are the only creatures capable of converting raw materials into organic foodstuffs. Thus, where conditions favour their luxuriant development, we may expect to find abundance of life. The tropical forests of those lands favoured with the combination of heat, light, and moisture are simply seething masses of living substance. On the land the limits are set by drought and cold. In the sea the limit is set by the absence of light in the great depths; but whilst life may be sparse there, it is not absent, for small quantities of organic matter may fall from other levels. The most abundant region of the sea is the shallow zone round the land where the seaweeds

abound, and the shallower seas. But the open sea, contrary to general belief, is quite well provided with the producers (green plants) as well as the consumers. One has only to dodge the bathers on an Atlantic liner and tip the bath-room steward to allow the bath water (sea water) to run through a bag of fine silk to discover this. The silk will filter out a mass of microscopic organisms, and the application of a powerful microscope to the deposit is startling. Here are all manner of the most beautiful creatures, some animal in their habits, others characteristic plants. Amongst the latter are diatoms, single-celled green plants. This floating life of the sea is called *Plankton*. It is also found in rivers, ponds, and lakes. The organisms composing it are, on the whole, microscopic, but its quantity must not be underestimated. In our home seas the greater abundance of plankton is usually responsible for the waters being green. At odd times in places the sea may actually bear a red scum owing to the abnormal development of some red planktonic organism.

The productivity of the Baltic Sea in plankton has been actually calculated and compared with land pastures; it is, of course, comparable in function and in composition. Hensen estimated that in terms of dry organic substance the yield in plankton of a given area was equal to five-sixths of the yield of that area of cultivated land. This may seem surprising at first, but then it must be remembered that production upon land is restricted to its surface; in the shallow seas an abundant plankton may exist down to the very bottom.

Most of the larger sea animals feed upon smaller fishes, molluscs, and crustacea, etc.; the cod, for example, feeds on small plaice, which feed, in turn, on small mollusca and crustacea; the porpoises feed upon herring and other fishes; others like the herring, and even very much bigger creatures like some of the

whales, feed upon plankton and have a special apparatus for filtering it (sifting it) out of the water. Twenty millions of microscopic planktonic organisms have been estimated in the stomach of a sardine! One meets with all kinds of food habits in the same group. The oyster depends upon the microscopic life which it filters from the water and wafts into its shell; the whelk crawls about in search of decaying animal matter, whilst a relative of both, the cuttle-fish, actively grapples with quite large crabs, pins them down, and sucks out their contents.

The sponge sets up a million little currents through the pores of its walls and filters out the smallest living creatures of the waters, all of them invisible to the naked eye. The worms of the seashore live on what they can obtain from amidst the particles of sand or mud they pass through their bodies. Their number on a beach is roughly an estimate of the organic débris in the sand.

On land one meets the same infinitude of feeding habits, and one might fill volumes with descriptions of great diversity. Every niche appears filled. Insects devour the leaves, the roots, the stems, and the seeds of plants. They chew their hard parts and suck their juices. Even dead and dried timber is not free from them, and what the white ants can do on a tremendous scale in Australia, Africa, India, and other tropical countries, the death-watch beetle emulates in this country. All our foodstuffs have their particular pests, and even our luxuries, like cigars and tobacco.

Some creatures are extremely restricted in regard to food supplies—the honey-bee, for example, to the nectar and pollen of flowers. This, however, is mild restriction compared with those insects which attack and suck the juices of one particular kind of plant. Contrasted with this is the cockroach, which will enjoy anything from old newspapers to beer. There are birds which live on fruit and seeds, others which

require and capture an incredible number of small insects, others which show remarkable skill in picking out worms, and, finally, the great vultures with their beastly habits of feeding on flesh. Many bats live on insects which they catch on the wing at dusk, others live on fruit (and are another of Australia's economic problems), and a few suck blood.

There is no point in going further, except to emphasise the fact that in all these diverse cases structure goes with habit, and one finds the most remarkable apparatus for food capture and its digestion.

Is it surprising to find that there is a host of animals which have adopted the plan of living in or upon other animals as parasites? There are undoubted advantages in this mode of life—the parasite is provided with shelter and surrounded with an abundant food supply. It has no strenuous search, nor does it enter into the perils generally associated with food capture. It is not remarkable that parasitic animals bear the characters of what we call degeneration—loss or poor development of the organs subserving the senses and the organs of locomotion. On the other hand, there are risks in parasitism. A parasite specially adapted to live on some particular kind of animal must make provision for its progency to reach this particular host in their turn. The risks involved in this are so great that we find parasites have remarkable powers of reproduction. The parasite itself must not (unless only a partial, temporary parasite) lose hold of its host, and both its food thefts and its production of poisonous excretions must be so nicely balanced that they do not kill the host, a result certainly equivalent to killing the goose that laid the golden eggs. It is very doubtful, therefore, if we can apply the term "degeneration" to such a nice degree of adaptation simply because in our eyes there is a loss of certain qualities.

Parasites may be external (ectoparasites) or internal (endoparasites). The former, of which the louse may

be taken as an example, are not nearly so specialised as the latter, an excellent illustration of which is the tapeworm.

Now, one must not jump to the conclusion that, wherever two organisms live in this very close association, one is a parasite upon the other. *Parasitism* in biology means essentially living upon another organism's activity, stealing the results of its labours, and giving nothing in return, often, indeed, causing disease, if not death. There are, however, strange partnerships in the animal and plant world (it cannot yet be claimed that we understand many of them) in which there may be mutual assistance, or one organism may benefit without the other being harmed. The terms *Symbiosis* and *Commensalism* have been applied to such cases, both of them so loosely that it is now difficult to define them. The first may be applied to extremely intimate relationships, the most famous of which is the *Lichen* of the plant world. Here, indeed, the relationship is so close that we speak of lichens as if they were one particular kind of plant, just as they were supposed to be years ago. Now we know, however, that a lichen is in reality an association of two lowly plants—an alga and a fungus. Each is essential to the other.

The common green hydra of fresh-water ponds is green because of minute green plants living inside some of the animal cells. It is supposed that the animal supplies the nitrogen, which is waste, whilst the plant cells produce useful supplies of oxygen and carbohydrates, the result of photosynthesis. Probably many of the tropical corals feed entirely in this way.

Now let us return to parasitism for a moment. The parasites which have come in for most attention during the last fifty years have been those responsible for disease in man and in his domestic animals and plants. There is unlimited versatility in this parasitism, for we find that all kinds of animal and plant groups

have some members which have developed parasitic habits. The most important human parasites are the *bacteria,* a few *fungi,* certain of the *protozoa* (causing sleeping sickness, malaria, etc.), and a number of different kinds of *worms* and *arthropods.* There are cases where parasitism seems to have no deleterious effect on the host. Unfortunately these cases are extremely rare. Usually there is some ill effect; occasionally it is very serious. There is, however, no mild acceptance of the parasite which thrusts itself upon the host, but frequently a reaction, and where resistance culminates in victory an *immunity* may be acquired by the host to further attacks from the same parasite.

CHAPTER III

PLANT AND ANIMAL TRANSPORT SYSTEMS—RESPIRATION

No organ in the body of an animal has captured man's fancy more than the heart. Pulsating day and night with its average beat of 75 times to the minute, about 39,420,000 in a year, its rhythmical beat has been accepted as the indicator of life, and, long before its true function was known, it was made the seat of the soul.

There are animals without hearts and without that system of tubes, the arteries and veins, which lead out of and into that organ. In the single-celled animals, and also in the lower multicellular animals, like the sponges, anemones, and even some of the "worms," food substances which have been captured and digested can, one might say, "ooze" through

the body. Once, however, the animal becomes more highly organised and specialised, a transport system becomes necessary. Heart and bloodvessels appear, although in the "lower" animals the system is very simple compared with that of, say, man. In plants a transport system is also necessary. The roots absorb certain raw materials and water, the leaves take in carbon dioxide and oxygen. These substances must be brought together and the products of their combination shifted about hither and thither, to be used here, stored there, or thrown out elsewhere. Man with all his ingenuity has not yet explained quite satisfactorily the mechanics of water movements in the passages of plants. Evaporation at the leaf surface and root pressures (the result of the living root cells taking in water from the soil) are insufficient to account for water reaching the tops of high trees, and we must look to the combination of these forces with the activity of the living cells of the plant for the power to lift tons of water per year (not an excessive estimate for a large tree). Compared with this, the animal mechanism is understood, although its regulation is complex. Not only does the human heart alter its beat rate to meet the varying demands of the living cells for food, oxygen and waste removal in rest and work, health and disease, but it is affected even by the emotions—love, fear, pleasure, or a stirring tale. And not only does its beat rate change, but its capacity may change, too, so that the volume of the contents forced through in a minute may be greatly altered.

Let us consider for a moment one or two muscle cells in the leg muscles of a man walking. Work is being done, and this is always impossible without a supply of energy. The living muscle cells require a circulatory stream for several reasons: (1) Being far removed from the regions specialised for the absorption of digested food, they require food material:

(*a*) to repair waste; (*b*) to be used as a source of energy. (2) They require oxygen, for oxidations enter into the processes involving release of energy. (3) Waste substances must be removed, otherwise the machine would soon be clogged. Now, wherever substances have to be picked up or set down the bloodvessels break up into finer and finer branches until a network of most delicate tubules is formed (called capillaries), through whose thin walls certain constituents of the blood can pass. It is difficult to find an analogy in everyday life, because although we convey gas or water through large mains from village to village, through smaller pipes in the streets and still smaller in the house mains, and so on, the gas or water eventually leaves the pipes through holes which terminate the system. Such is not the case in the higher animals. The vascular network is complete. Large vessels (arteries) with thick impervious walls leave the heart, and these branch and rebranch into smaller and smaller arteries until eventually networks of delicate capillaries are produced; but from these networks small veins are formed which join up with their fellows to form larger veins, and these again may join up with others until the largest veins are reached which enter the heart. Anything leaving or entering the system must pass through the walls of the bloodvessels where they are adapted for that purpose (the capillaries). In addition the capillary network provides a mechanism for extending the area of blood in contact with the tissues.

A pump and a system of tubes to all parts of an animal would be a very rigid device unless there were means of regulating the flow. An organ requiring a large circulation of blood must have large vessels, and the demand must vary according to the work being performed. There are occasions when the bloodvessels of the stomach and intestines should be well filled, others when the muscles require all

the blood they can get. The mechanism is simple and efficient. The walls of the vessels, even of the capillaries, are contractile, and the lumen may be constricted. This at once cuts down the flow. The regulating mechanism is very sensitive, as will be obvious when it is pointed out that a blush is due to relaxation of the superficial skin capillaries of the face and pallor, due to cold or fear, is consequent upon their constriction.

So, by constricting here, relaxing there, and varying the intensity of action of the heart, the circulating fluids arrive where required in suitable quantity.

The blood system is not so complete as this in many invertebrate animals.

If food storage is required in the animal body, and this is more or less universal, for there are always bad seasons to be faced or strenuous periods—emergencies of activity—to be met, the soluble sugars of the circulating fluids are converted into insoluble compounds, and here there is a striking point of resemblance between animals and plants. In plants foodstuffs are transported as sugar and stored as starch; enzymes are present to facilitate the change wherever required. In animals the starch is Glycogen. Fats are also store substances. Proteins are less frequently found as stores, at least in animals.

Now let us turn to a function—*Respiration*—which is so characteristic of living things that evidence of its existence in man is taken with the heart beat as a sign of life. Modern discovery, as well as modern habits of life, have attracted considerable attention to the phenomenon of respiration. The athlete, the flying man, the mountaineer, and the diver have all been concerned in its investigation.

The general idea is that respiration—*i.e.*, breathing in the case of man—means the mere intake of oxygen and the output of carbon dioxide. Actually respiration is the complete passage of oxygen *to all*

parts of the body of an animal or plant, and the output of some of the products of combustion—viz., carbon dioxide and water, which happen as a rule to take the same road. It is often assumed that respiration is analogous to the burning of coal in a furnace, and that any production of energy demands its presence. The idea is founded on the fact that most living cells are continually using oxygen, and that where increased activity takes place there are greater demands for oxygen and more carbon dioxide is produced. Actually muscle contraction is due to chemical changes *which do not require oxygen at all.* Oxygen is required *after* the contraction, during the period of relaxation of the muscle when certain substances are being removed.

Living cells can often support absence of oxygen for a little time. Still the fact remains that oxygen and oxidation are essential, except in a few cases, and respiration remains one of the most characteristic phenomena of life. The point of modern discovery is that it is not "the prime mover in the life processes, but an accessory which enables them to continue. Its utilisation provides energy which, so to speak, winds up the machine for a new run."

Plants and animals living submerged in a fluid medium (sea, pond, river, or aquarium tank) obtain their oxygen from supplies dissolved in the water, except in the case of animals which come to the surface for air. Other creatures depend upon the air for their oxygen supplies directly. Single-celled organisms and the more simple animals absorb oxygen through the general surface of the body. Increase in size and complexity, with many cells packed close together often accompanied by the presence of a somewhat impervious outer coat, hinders this and renders a special region necessary for oxygen intake. Such regions are the *Respiratory Organs,* which are structures where the internal fluids of the body can be brought into

very close contact with the outer medium. They are likely to be rather delicate; the respiratory surfaces will be certainly delicate and of necessity kept moist. They are most frequently greatly folded extensions of the outer surface, and one finds that whilst they project outwards in aquatic animals (where they are termed gills), in land animals they are tucked in (lungs and other organs). The efficient area which may be developed in a confined space is surprising. It may be illustrated by the fact that the area of the human lung surface active in respiration is somewhere near 1,000 square feet. The tiny leaflets of a fish's gills are present for the same purposes; they cannot present their area to the outer oxygen-containing medium unless freely separated from each other. Taking a fish out of water generally results in asphyxiation, because, whilst actually brought into contact with a greater oxygen supply, the gill leaflets, not being supported, lie on top of each other and the respiratory surface is greatly reduced. Some method must be found for changing the medium surrounding or within a respiratory organ. Thus gills are waved about, or are extended in water currents, or there are special movements for setting up currents over them. For the same reason all animals with lungs have breathing movements by which these bags are rhythmically emptied and filled.

All this leads to a consideration of the circulating fluid which carries the oxygen. In some of the invertebrate animals the blood appears but little different from the sea water, and can only carry as much oxygen as can be dissolved in water. In others (many of the worms, cuttle-fishes, crabs, lobsters, etc.) and more particularly in the vertebrate animals the blood is much more efficient as an oxygen carrier by reason of the presence of chemical substances specially suited for this purpose. The best known and by far the most important of these are *Hæmocyanin* (in cuttle-

fishes, crabs, lobsters, and many other molluscs and crustacea) and *Hæmoglobin* (in vertebrates). The first named is a protein combined with copper and is blue, the latter is a protein combined with iron and is red. Thus the colour of the blood is due to a substance which is in the highest degree important in respiration. The value of hæmoglobin depends upon its peculiar property of combining under certain conditions with oxygen forming oxyhæmoglobin (bright red in colour), and yet being capable of giving up all this oxygen again (oxygen dissociation) under other conditions. This see-saw can go on indefinitely. Combination with oxygen takes place where free oxygen is present, and depends upon its pressure and upon five other variable conditions (amongst which the carbon dioxide present and the degree of alkalinity or acidity of the blood may be noted). This sounds rather complex, and it certainly is. Put in a nutshell, however, it means that blood containing hæmoglobin will take up a considerable quantity of oxygen when flowing through the capillaries of a respiratory organ and with equal facility will give that oxygen up again when in contact with the living tissues which are requiring it.

We may now try to apply these fundamental features of respiration to the practical side, and here we must stress human problems.

A man is resting, reading a book on a couch. His breathing is slow and regular, and he is practically unconscious of it. His heart is beating 70 to the minute withdrawing blood from the veins and pumping it out into the arteries. At every beat 70 cubic centimetres of blood are pumped out, say $8\frac{3}{4}$ pints per minute. The man gets up and proceeds to walk; his pulse rate automatically increases and so does his breathing. He runs and runs hard, and his heart beat increases until it may reach 150 per minute. At the same time the blood output from the heart *at each*

beat increases, say 120 c.c. is reached. The heart is now pumping almost 4 gallons per minute! This automatic increase is to meet the increased demands of the living cells, chiefly the muscles which are involved in the work done, to bring them oxygen and to carry away the waste products of oxidation. The flow of blood through the lungs has increased to such a point that the lungs must be emptied and filled with air far more rapidly in order to provide a sufficiency of oxygen. Our runner now stops, but his heart beat still continues to be rapid and the panting for breath goes on for some minutes, only gradually slowing down.

What caused the heart and chest movements to increase in speed as muscular exercise commenced? Why did not both fall to the resting condition immediately the man stopped running?

The explanation so far as we know at present is the following: With each contraction of the muscle fibres chemical products appeared (lactic acid amongst others) which had to be oxidised. One result of this oxidation was the production of carbon dioxide. The presence of lactic acid in the blood, as also of carbon dioxide in the smallest of the lung chambers and in the blood, was a stimulus to the mechanism (the nervous system) occasioning increased heart beat and chest movements.* We now see why these were automatic and out of the control of the will. But having reached a certain point, the respiratory exchange was still insufficient to meet the enormous demands made by the athlete's greatest effort. This did not prevent his continuing. He obtained his energy by the breaking up of carbohydrates in the muscle and the lactic acid accumulated since there was insufficient oxygen to oxidise it. Hence, although he stopped run-

* Probably much still remains to be discovered regarding this regulation.

ning, the panting for breath continued; the man had incurred an oxygen debt, and respiratory activity continued higher than normal until once again the constitution of the blood and tissues became normal.

Curious respiratory problems are involved when a diver descends in one of the ordinary rubber diving dresses. In order to counteract the pressure of the water on the dress, the air received by the diver must be under a like pressure. The composition of the air in the helmet will, however, depend upon the *rate* of supply, and the respiratory activity of the man. Suppose that the result is the production of 2 per cent. carbon dioxide in the air of the helmet. The effect of this will vary according to the depth. At twenty-two fathoms it would really be equal to five times that percentage at the surface and would exert the same influence as that amount; it would *stimulate* the respiratory regulating mechanism to greater and greater efforts and the man would pant for breath. Yet there would be actually no lack of oxygen; on the other hand, this, too, would be at far higher pressure than at the surface. Serious danger would, of course, result. The remedy is to increase the *rate* of air pumped down as the pressure increases, so that the carbon dioxide is more quickly removed. Conversely to the above, a flyer ascending in an aeroplane passes into regions where the air pressure is reduced; there is less air each time he fills his lungs, less oxygen, and *less carbon dioxide*. He should therefore breathe more rapidly in order to obtain a sufficiency of oxygen. Instead, the lack of carbon dioxide actually tends to reduce the breathing rate. Thus the surprising feature that the man suffers from lack of oxygen, without at first realising it, because the breathing rate is unaffected. With continual reduction in air pressure the conditions again change; events then become more dramatic!

These two respiratory examples show how beau-

tifully regulated is the animal mechanism and the effect of abnormal conditions in putting it out of gear.

The respiration and oxygen consumption of different animals is as variable as is their organisation and activity. There is indeed little resemblance to the often quoted analogy with a fire. Give a burning candle more oxygen and the rate of combustion increases; reduce the quantity and combustion decreases. As a general rule, for the higher animals at all events, if the supply of oxygen is increased the rate of combustion in the body does not vary. The same applies to reduction unless the point is reached where a further drop renders the oxygen supply insufficient for the animal's requirements.

There are always interesting exceptions in biology, and so far as respiration is concerned these are supplied by creatures which do not require oxygen at all; indeed some of them are hindered by its presence. They are called *Anaerobic* organisms. Some extreme examples are found amongst the bacteria, and one of these is the bacillus of tetanus (lockjaw). To grow a culture of this germ, which is found in well-manured soil, one must cover the culture fluid with oil to keep the air away or pass some gas like hydrogen into the culture flask to drive out the air.

Parasites of such high organisation as the tapeworms, which live in the intestines, are also anaerobic.

If we consider the case of the muscle cells already quoted, we shall realise that there is not an absolute difference between the anaerobes and the aerobes. In both cases energy is set free by the breaking down of complex substances — proteins to amino-acids, starches to sugars, sugar to acetic acid, sugar to alcohol, and many other types. This, however, in aerobic organisms provides only a small amount of energy compared with that set free by oxidation.

Completely anaerobic organisms have to do without the latter.

Let us now sum up the position we have reached in regard to the mechanism of living organisms. The activities of protoplasm, which we may regard as a complex of systems, require the constant supply of certain chemical substances—proteins, carbohydrates, fats, mineral salts, and water. Green plant cells alone can manufacture the proteins, carbohydrates and fats from simple substances (carbon dioxide, water and mineral substances), but special energy is required for this and is obtained from the sun in the form of radiant energy. Energy is required, however, for the constant change, which is the characteristic feature of living protoplasm (also for growth, and particularly in animal cells, for movement and heat production). This is obtained wholly, or more generally in part, by the splitting of the complex substances enumerated above. In the majority of cases the substances so produced are oxidised to carbon dioxide, water, etc., with another release of energy, and waste substances are produced. On the green plant side the latter are mainly the products of oxidation of carbohydrates and fats. On the animal side waste nitrogenous products play a much greater part, and so we find excretory organs specialised for their removal. If the protoplasm is in direct contact with a medium capable of supplying all the above needs directly, a relatively simple organisation suffices. With aggregation of cells to form larger organisms it is necessary to carry substances to and from the cells which are out of contact with the external medium. This occasions the development in the multicellular animals of a respiratory system, a circulatory system, and a heart. The multicellular plant in the same way develops a conducting system, rootlets for the absorption of mineral salts in solution, and leaves for the absorption of carbon dioxide.

And now for a final statement which is the corollary of the above. Animal life is characterised by great energy output and the breaking down of complex chemical substances which release this energy. On the other hand, the fundamental characteristic of the green plants is that they produce these compounds of greater energy, the energy required for this being obtained from the sun. This transference of radiant energy into chemical energy and its storage in plant matter is essential for the existence of the higher forms of animal life, and during the last generation has been at the bottom of man's industrial development (the coal age).

CHAPTER IV

MOVEMENT AND ITS CORRELATED FEATURES

From ancient times movement has been associated with life, and even to-day the two words are often made synonymous. The power of locomotion, which is one expression of this property of protoplasm, is, however, the exception amongst adult plants whilst characteristic of animals except for a few types which live firmly fixed to some substratum (sponges, corals, zoophytes, barnacles, etc.). The actual shape of living creatures is closely associated with locomotion. The shape of a fish like the mackerel is admirably adapted to rapid movement through water; one could not conceive of a starfish performing like movements. One may assume, in fact, that the presence of bilateral symmetry—right and left sides, a top side and a bottom side—was developed in connection with pro-

gression in one particular direction. Where radial symmetry occurs in the animal world, it is found amongst attached or floating animals. And if one end of an animal is always foremost in progression, what would be more likely than to find that that end, always coming into contact with the environment first, should be most sensitive? In fact, amongst multicellular animals movement in this way is almost always associated with some sort of a "head."

Movement in the higher plants is limited to the movement of parts, to the circulation of fluids and protoplasmic movements in the cells. The former can, however, on occasions, be rapid enough to be very obvious, as, for example, the collapse of the leaves of the sensitive Mimosa on being touched. Many single-celled plants can swim actively, and frequently certain plant cells, the sex cells which are set free, are just as mobile as those of animals.

Locomotory movements in animals are achieved (*a*) by a flowing movement of the protoplasm, (*b*) by the lashing movement of extraordinarily fine processes from living cells, and (*c*) by the contraction of fibrils of specialised protoplasm. A muscle cell presents the greatest development of this fibrillar structure. The first method is confined to unicellular organisms. The second type (movement by cilia or flagella) is also most frequently found amongst the single-celled organisms, but there are higher animals whose locomotory movements are due to a covering of cilia, and still more frequently their early stages move by this means. Both these locomotory mechanisms require a watery fluid, and so they are confined to creatures living in water or to parasites within body fluids.

The third type of movement is at once the most important and the most fascinating. The majestic flight of the albatross, the graceful pirouette of the ballet-dancer and the gorgeous sound of a Beethoven symphony are all produced by muscle movements!

The occurrence of delicate fibrillæ in the protoplasm of the single-celled creatures may be regarded as the first indication of muscle. In the animal group, to which the jelly-fishes belong, there are cells in which the fibril development is much more advanced, and one can speak for the first time of muscle cells. They tend to grow exceedingly in length until they become fibre-like. A large limb muscle, such as the human biceps, is made up of bundles of muscle fibres, and each fibre consists of several cells. The contractile matter in this case is likewise found in the delicate fibrillæ.

The wonderful feature of the fibrils is not that they can contract in length as the result of a stimulus, but that alternate contraction and relaxation is possible, and that such alternations may reach the extraordinary velocity of 250-300 per second. This is the case in the muscles which move an insect's wing during flight. The muscle fibre does not contract essentially in volume when it becomes shorter. Every boy knows that the contraction of the biceps muscle when the arm is bent at the elbow is accompanied by an increase in its girth.

What sets the fibre contracting? What goes on inside the fibre when it contracts? Where does the power come from? In the lowest forms where muscle fibrillæ are first developed contraction may result from many different sorts of stimuli, affecting the cell containing them. The contraction of the muscles of higher animals is normally brought about by nerve impulses conducted to them by nerve fibres, but in a muscle nerve preparation (muscle and its nerve taken immediately from a frog which has been killed) various kinds of stimuli—electrical, chemical, mechanical—may produce contraction if applied to the nerve or the muscle direct.

Compared with our mechanical instruments for doing work, the muscle is very efficient indeed. Its

efficiency has been calculated as 25 per cent. against 20 per cent. for an efficient engine. Early experiments showed that any increase in muscle activity was accompanied by greater respiratory exchange; oxygen was used and carbon dioxide produced. Hence the assumption that energy for muscular *contraction* was obtained by the combustion of muscle substance. Now, combustion in everyday life is usually accompanied by heat. It has been possible by the invention of extremely delicate electric methods for the determination of heat production to find the amount produced by a muscle fibre at every stage from stimulation to relaxation. Application of these methods shows that the initial heat production which takes place when a muscle fibre begins to contract occurs even though oxygen be absent altogether. It is, in fact, associated with energy production by "breaking-down" chemical changes; oxygen is quite unnecessary, and not a party to these at all. The story of muscle chemistry may be suggested as follows. The muscle before contraction contains practically no lactic acids; its cells are consuming but little oxygen (merely the amount necessary to sustain the normal processes going on in the protoplasm). A nerve impulse comes, the muscle contracts, heat is produced, various chemical changes occur, and lactic acid appears. Then oxygen is required, the lactic acid is oxidised, and carbon dioxide is produced as a result. But what is the material whose breakdown gave us the lactic acid? Experiments seem to show that it is carbohydrate. Here we must leave the subject, you will say just having reached the most intriguing point. That is true. The knowledge that glycogen or sugar carried to the muscles by the circulation is the substance whose breakdown provides the energy for muscle contraction does not explain how a muscle fibre shortens. The exact mechanism by which the chemical energy is converted into the mechanical energy of shortening is still awaiting discovery. We do realise, however, why a

muscle contracts without oxygen, and why oxygen is necessary before it can contract again. We can understand better why the athlete's effort soon has to come to an end, although he can run again after a period of rest. He has, in fact, accumulated such an amount of lactic acid that further muscle activity is hindered until it is oxidised away.

In order that muscles may exert their power to the best advantage in the production of definite movements, they must be definitely arranged in the body, and for the greatest efficiency a firm attachment is usual. They are brought into relationship with skeletons, which serve not only to support what would otherwise be shapeless masses of living tissue and to protect delicate organs, but provide the muscle attachments and levers, the jointed framework upon which the direction of muscle pull may depend.

In a few cases muscle pull is against fluid or an elastic ligament. More generally one finds one muscle pulling against another. Contraction of one is simultaneous with relaxation of the other.

Where parts of plants move, the mechanism is rather different from muscle movement, and is due to tissues contracting or stretching owing to changes in the amount of water in the cells, which may be turgid or flaccid. The very active movements of the sensitive plant and the morning and evening movements of certain leaves and flowers are due to such variations. More rapid movements still may be due to cells exploding as the result of water absorption.

It might seem rather unnecessary to devote even a line to the reasons for animal locomotion. Whether it is a matter of instinct or intelligence, one would assume that animals moved so that their environment remained most satisfactory from all points of view. Some of these locomotory habits are, however, more than usually interesting, especially the migrations which appear associated with reproduction. The

migration of birds is the most familiar of these, and stories of the extraordinary 2,000-mile flights from the northern to the southern hemisphere are amongst the most intriguing features of natural history. The birds nest and produce young in one district and live in the other during the non-breeding season. Generally the nesting district is in a colder climate, and the winter season there may be too difficult for the birds. The big puzzle is—how do the birds find their way? To make it more difficult it may be added that the young birds who have never made the journey before fly back without the company of the older birds and parents.

This is only one of a number of similar migrations equally startling. The eels of European rivers pass out into the sea (a change of water which would kill most fresh water animals) and swim hundreds or thousands of miles, until away in West Atlantic waters they breed and probably perish. That is wonderful, but still more astonishing is the fact that their delicate larvæ (early stages) make the journey back, and eventually enter the rivers of Europe. How do they find their way? What is the guiding principle? It is much more difficult to conceive of a mechanism in the case of a slow-moving creature, taking months to cover the distance, than in the bird examples where rapid flight reduces the journey to hours or days, and the environment changes quickly. Many other fish in the sea and smaller creatures with poorer powers of locomotion move from one type of marine environment to another at the breeding season. All the examples provide the same puzzle.

The force a muscle can exert is probably chiefly dependent upon the number of muscle fibrils in the muscle, and thus upon the sectional area of the muscle. This is worth keeping in mind, for it will help us to understand some of the remarkable tales about the enormous power of certain animals. A flea, for example, can jump six or eight inches (no, my friend, I

don't believe yours went further). Since a flea may only weigh $\frac{1}{78000}$ ounce, it is not surprising that people have calculated that a man equally powerful could leap 36,800 miles! There is a "catch" in the example. It would be true to say that a man with the same power to weight ratio would have very much greater powers of leaping than he has at present, but in order to have this power each one of his muscle fibres would need to be many times more efficient than those of the flea. The reason for any very small creature's feats of strength is that with simple increase in size the volume and weight increases as the cube of the linear dimensions whilst the sectional area of the parts only increases as the square.

CHAPTER V

SENSITIVITY AND REGULATION

Out in the back blocks of Australia I once saw a Chinese cook neatly chop off the head of a hen that was ultimately to grace my dinner-table. To my horror the headless animal ran almost perfectly about 20 feet before collapsing. That movement involved the harmonious action of a large number of muscles. What controlled them and what set them in motion?

It is said that a bat, if confined in an absolutely dark room across which wires are stretched, will fly round without touching any of them. How are they perceived? A clever sight reader sits down at a piano with a new piece of music. How are the black marks on the piece of paper translated so rapidly into finger movements and possibly beautiful sounds?

If a little gunpowder is spread out to cover, say, an

area of two or three square feet, and a lighted match is brought into contact with it at one point, a rapid change, accompanied by flame and smoke, would pass from that point throughout the mass. It would not be simultaneous, a fact which might be more clearly brought out by laying a long trail of gunpowder and noting the time it took for the flame to pass along it. Striking the gunpowder with a hammer at one end might produce the same effect. We can speak of this reaction to flame and shock as sensitivity. Some very unstable chemical compounds—chloride of nitrogen, for example—are much more sensitive than gunpowder.

It is very characteristic of living protoplasm that it is sensitive to change in its environment, and mere contact, a chemical or a physical change (temperature, electricity), may set up some complex readjustments which pass in the form of an impulse throughout the mass. If the stimulus is very great, a large and irreversible change may take place in the protoplasm, bringing disorganisation and death. (This might be compared with the change in the gunpowder.)

The life of any mass of protoplasm, small or large, is the epitome of its sensitive readjustments to all kinds of changes taking place about it.

Now, if we want to make sure of an explosive being set into action by a small force delivered at one particular spot, it is customary to use some particularly sensitive and violent reacting substance in the form of a detonator. In an analogous manner one finds specialisations of protoplasm, either in a cell, or more frequently a whole cell, which are particularly sensitive. This development goes, however, much further than anything in our analogy, for the protoplasm can become so adjusted that it is only influenced by one kind of stimulus. Here one finds protoplasm sensitive to light, in another place sensitive to substances in solution. We speak of these regions in the

higher animals as the *Sense Organs*. They become the intermediaries between the organism and the external world, especially where the sensitivity of other surfaces of the body may be reduced (as, for example, where covered with some protective armour). It must not be forgotten that in the higher animals, where special sensory cells are developed, the protoplasm of other cells not directly stimulated often retains something of its fundamental property.

The highly developed sensitivity of the protoplasm of sensory cells is startling. One might stress as an example the wonderful efficiency of the eye; instead, let us remind the reader of a simple organ, the nose, which scarcely seems to reach in man the efficiency attained in lower animals. Yet it is possible for the human nose to recognise the presence of $\frac{1}{460,000,000}$ of a milligram of mercaptan in 50 c.c. of air! It is doubtful whether the chemical analyst with all his delicate apparatus can beat this.

One cannot discuss the sensitivity of animals and plants without bringing in the extraordinary mechanisms of regulation exhibited by them. In fact, it is the manifestations of the co-ordinating systems which have always favoured the belief that a living creature is something more than a machine driven by physico-chemical forces. In the simplest organisms we have seen that the protoplasm may be easily affected by external stimuli, so that some change takes place in its ordered systems. This change passes through the protoplasm (*cf.* our analogy of the gunpowder). From this fundamental property of protoplasm one of the higher systems of regulation has been evolved. The passage of an impulse through the protoplasm of all sorts of cells in a multicellular animal organism would probably be slow; it would certainly be too diffuse. Contact of, say, the middle of the back with a red-hot poker suggests *immediate* and properly regulated action on the part of the arm and leg muscles! Quick

response is enabled by chains of specialised cells, which form definite paths along which an impulse passes quickly. The cells are *Nerve Cells,* and they make up a more or less complex *Nervous System.* The nature of the change in the protoplasm of nerves, which travels like a flame along a train of gunpowder or the electric current along a wire, remains to be discovered. The impulse runs moderately fast—four miles per minute—but nothing like so fast as an electric current.

The beginnings of animal sense organs are seen in the protozoa, but there is no steady development as one proceeds through the animal series along any line that we may suppose evolution took. Though, perhaps, in the vertebrate animals we find their greatest efficiency, there are many exceptions. Wherever animals are most active and live most openly we find some sense organs well developed. Thus there are very active marine worms with eyes relatively as well developed as those of fishes; on the other hand, the earthworm has nothing but scattered sensory points in its skin, which enable it to distinguish light from darkness. The active cuttle-fish has well-developed eyes; its sedentary relative, the oyster, has none; the snail comes in between these two extremes. The frog has obvious eyes, whilst another amphibian—Proteus, of the caves of the Tyrol—has none at all. Internal parasites, notoriously deficient in sense organs, have neither to flee from enemies nor go in search of food. It is tempting to theorise on this. Did the activity and the greater needs bring forth the efficiency of protoplasmic receptors in animals whose habits seem to require them, or was it the other way about? Can we find evidence that the active habits are the result of a more perfect "awareness"? The relatives of many parasitic animals are well favoured with sensory structures and would indicate that loss of these occurred with the adoption of parasitism. Even this might be

interpreted the other way round, however, and there is quite a difference of opinion as to whether cave animals lost their eyesight as the result of living in darkness, or whether they were practically blind originally and found a refuge in dark places, where loss of eyesight was no disadvantage. These are the little problems that crop up when one thinks of animal evolution.

The first trace of what may be regarded as an eye appears in some of the single-celled creatures as a tiny spot of red pigment. Here there can be no question of seeing anything, but one may assume that the pigment, absorbing light, renders the protoplasm more than usually sensitive to it. More organised pigment masses are found in the cells of jelly-fishes. Next we find some means of focussing the light by means of a lens on to the pigment containing cells. This brings both direction and concentration of light rays with it. Finally, we have animals in which large numbers of specialised light receptor cells are aggregated together in a retinal layer and provided with lens and focussing arrangements, so that sharp images of the environment are thrown on to it. In the lowest cases vision is probably simply a matter of responding to light and shade. At the other extreme are the wonderful eyes of the cuttle-fish, of the insects, and of vertebrate animals. Their structures may vary exceedingly, but the mechanism remains very like the ordinary camera—a lens, a focussing arrangement, and a retina of specialised cells whose protoplasm is readily affected by radiant energy.

The other sense organs may be traced in similar ways, although, with the exception of the ear, it would be difficult to show such a long series of types and stages. The organs of taste consist of collections of cells in which the normal sensitivity of protoplasm to chemical substances in solution is greatly heightened. It may even be specialised, so that sensitivity to par-

ticular substances is greater than to others. The olfactory sense is difficult to separate from taste in aquatic animals, because the only medium touching the animal surface is water.

In everyday life it is usual to speak of five senses. The number is larger than five; one or two are not generally realised to exist, and others are confused under the sensation of "touch." The protoplasm of the unspecialised single-celled organism is sensitive to contact and to changes in temperature. In man, however, there are special sensory receptors in the skin for mere contact, for temperatures warmer than that of the skin, for temperatures lower than the skin, and for pain; and it is possible to map out these minute sense organs by touching the skin with a point (at normal temperature, or warmed or cooled, as the case may be). Senses not recognised by the public include one which is met right through the animal kingdom and is often associated with the entirely different sense of hearing. We refer to the sense of *Orientation*. It may be granted that, as a rule, human beings feel that they are in this or that position in regard to the earth about them by means of their eyes or by contact. There is, however, another organ which relates the body to change of position in space. In the crab and lobster it is a relatively simple bag. In man it is a system of three canals and associated parts connected with the ear. We cannot describe complex structures like these without pictures. We may say, however, that the organs of orientation generally consist of little particles of secreted substance or of sand grains from the outside world, balanced delicately in a chamber upon the hairlike processes of sense cells in the wall of the chamber. If the animal is turned upside down, the particles rest and press upon other sense cells, and this contact stimulus is the trigger.

Is it possible to find specialised sense organs and a nervous system in plants? Certainly there do not seem

to be any very obvious structures for the reception of changes in the environment, like animal sense organs. Yet roots grow down, stems grow up and also towards light. Rootlets are attracted by and grow in the direction of moisture. Leaves and flowers perform diurnal movements, and so on. A fly caught on a leaf of Venus' Fly Trap causes the leaf to fold over it, and Mimosa, the sensitive plant, very quickly responds to touch. We often take all this for granted, until we see how a bean seedling, growing in damp sawdust in a box, will respond time and time again to our treatment if we take it up and place it with its root tip pointing upwards. It can easily be shown that for some reason or other the protoplasm of root tip and stem tip is sensitive to the force of gravity. The response is different, however, and one grows towards the pull, the other away from it.

It is generally believed by botanists that there is nothing resembling the animal nervous system in plants. Where a stimulus to one part is followed by the response of another part, it is assumed that as a result of the normal sensitivity of living protoplasm the part stimulated has either produced some chemical substances which are carried to the region of response or that a hydromechanical disturbance is set up. In the latter case a change in the turgidity of a cell affects its neighbour, and this affects the next one, and so on. We might almost liken it to the passage of a pulsation through a water-pipe filled with water. It should be noticed that the first-mentioned process, the translocation of a chemical substance, is found in animals too, and we shall describe it later.

Efforts have recently been made to show that the passage of a response in a plant is quite similar to that along an animal nervous system. At present, however, the botanical world appears to stand unconvinced.

We have seen that the rapid and harmonious response of parts of a multicellular animal to stimuli

affecting some (possibly) distant part of the body is bound up with the presence of a special system of cells, the *Nervous System*. In man and other vertebrate animals, from the fishes upwards, the central nervous system is the brain and the spinal cord; in the invertebrate animals the central nervous system never has this form. Where highly developed, it most frequently takes the form of two masses of nerve cells and fibres in the head and two cords running the length of the body, but ventrally, not along the back as in vertebrates.

Such types of nervous system did not appear all at once in animal evolution, and some of the lower animals provide us with an inkling of the steps that might have been taken. Thus in the jelly-fishes and their allies there is no central nervous system as distinct from the peripheral system. All we have is a network of special cells under the superficial bounding cells of the body, and this network consists of nerve cells. The higher types may have arisen through the grouping together of nerve cells. Whatever may have been the history, the nervous system comes to consist of aggregations of cells, many of which have one or two exceedingly long processes, which pass out to relatively very distant parts of the body. A nerve is a collection of these long processes (nerve fibres), each of which is a path leading to some particular destination. It is a remarkable anticipation of man's modern scheme of telephone cables, in which the wires from very many houses are collected together in one thick cable and taken underground to a central station.

Perhaps the nearest thing we have to a nerve impulse is an electrical current running along a wire. Let us take this analogy further. One of the most common and simple schemes in everyday life is an electric bell "circuit." We press a button, the current runs round a closed circuit and is translated into movement at an electric bell. The whole thing is as auto-

matic as pressing the trigger of a loaded gun and setting forth on its journey a rifle bullet.

Now, it is quite conceivable that we might have a nerve circuit of a similar type. A contact—simple touch, chemical substance, or light ray—with a sensory cell might send an impulse along a definite path to terminate in a muscle fibre and cause contraction. The whole thing could be automatic, so that stimulus of the particular sense cell would be certainly followed by contraction of the muscle fibre. Two nerve cells at least would be required for the circuit—one the sensory cell with its long process, and a motor cell linked with it and with a process stretching along to the muscle fibre. This is our simplest nerve circuit, but it is probably only hypothetical. It is a valuable conception, however, and the type of activity at least is an actuality. We call it a *Reflex Action*. To be nearer the truth we must make the path a little more complex without changing the automatic nature of the response. We must bring the termination of the process of the sensory cell into contact with more than one motor cell. Most reflex actions would involve the stimulation of several sensory cells at once, and so a number of paths would be involved. The essential is that a circuit is traversed automatically by nerve impulses, and an involuntary action results as certainly as the electric bell rings when the outside push is pressed. Concrete cases are easy to find. A sudden movement made in front of the human eye causes a rapid, involuntary eye-blink. This is a reflex action.

Now, it is possible to make an extremely complicated machine in which many final movements follow certain initial actions. Pressing a button might set a newspaper printing machine in action, which not only prints, but folds and cuts the separate copies. The automatic telephone is another example. All we have to arrange in these cases is that one movement sets off another. Automatic controls might regulate the action.

Given such a type of activity in a living animal, we should regard its complete behaviour as the expression of a set of co-ordinated reactions. There would, of course, be no place for "learning" or "experience," any more than in our machine. To what extent can the activities of the multicellular organisms be interpreted along these lines? We might conceive of the responses of a jelly-fish being entirely automatic. The animal is carried hither and thither by currents in the sea. All it does itself is to keep floating by movements of its bell (like opening and closing an umbrella). These movements result from the rhythmic contraction of muscles which are connected up by nerve cells to little sense organs situated round the margin of the bell. If the jelly-fish is tilted by wavelets one way or another, or becomes turned upside down, the sense organs receive certain stimuli and impulses are passed to the muscles, which right matters. A submarine or aeroplane might be provided with a stabilising mechanism working very similarly.

Now, in the human being we have, added to this automatic and involuntary type of activity, consciousness, memory, and voluntary action. It is clear that certain cells of the nervous system are responsible for this advance, and it is equally clear that they are collected together in that part of the nervous system called the *Brain*.

It is beyond our bounds to pursue this matter further, except to indicate that involuntary and voluntary actions are closely associated. Two excellent examples are walking and riding a bicycle. Each activity is the result of hundreds of muscle movements all beautifully co-ordinated. One follows another, and one is possible only when another has taken place. *Both activities must be learned*. We sit on a bicycle, and this and that sense organ is brought into action. The brain builds up its conscious picture, and we painstakingly perform this and that voluntary movement.

It is a matter of will. Then gradually the actions become automatic and involuntary until the day arrives when we can cycle along the street, balancing, steering, and moving forward, and at the same time thinking deeply of the holiday we are going to enjoy next summer or the hat we intend to buy next week. Cycling has become a machine-like series of reflex actions.

What has happened here to make involuntary reflex actions and automatism carry on what was impossible at first, and are we to regard the complex activities of the lower animals as unconscious co-ordinated reflex actions (like riding the bicycle automatically) or as involving consciousness and will? The first of these questions is much more easily answered than the second, and we may postulate that, with repetition of " messages " along the same paths, these become (like well-trodden paths through a wood) more readily traversed, until finally all the varied stimuli resulting from a seat on a bicycle automatically release impulses along the proper nerve fibres. It has been suggested that conscious processes of higher animals are associated with the activity of very many cells in the cortex of the brain. If such is the case, one would be justified in regarding the activities of the lower animals as built on reflex actions alone.

We must try to find a few lines to describe " remote control " (as our wireless enthusiasts call it) in the animal by the conduction of chemical substances from one part to another. Curiously enough, this method, which is put forward by the botanists as one of the possible explanations for passage of an impulse in plants, has only been fully appreciated in animals during the last twenty-five years. Possibly the ease with which the nervous system may be seen and dissected out in animals accounts for this.

The chemical substances, whose passage from one part to another is responsible for control or initiation

of some activity, are found in internal secretions, and have been called *Hormones* (ὁρμάω—I excite). Probably every organ in the body, and possibly every cell, is connected chemically with the rest. In speaking of hormones, however, one thinks first of the examples where a definite secretion is very striking. These chemical messengers have so far only been demonstrated in the vertebrates where they are carried by the blood stream. Some of them are produced by organs which play other functions as well. The best known of these are the reproductive organs, which not only produce germ cells, but secrete into the blood substances which control the development of other characters of the body secondarily associated with sex. In man the presence of the reproductive organ hormones determines the change in the voice at puberty and the development of hair. The plumage of birds may be so changed by removal of the reproductive organs that a female bird may come to look exactly like the cock bird. The secretion of digestive juice by the pancreas is set going by the passage via the blood of secretin, which comes from the walls of the intestine and is itself produced by the arrival of partially digested foodstuffs from the stomach. The most interesting of all these secretions come from the *Ductless Glands*, such as the Thyroid, Pituitary, and Adrenal (or Suprarenal) Glands, etc. It seems almost certain that the temperament of different people is largely determined by the balance of the secretions of these glands. A very small amount indeed of Adrenalin, a hormone of the suprarenal, injected into the blood, causes a rise in blood pressure and quickening of the heart beat. The whole effect is to make the animal more ready for an emergency, ready to fight, or to make the speedy reactions characteristic of efficiency.

CHAPTER VI

REPRODUCTION—GROWTH—DEATH

The power of reproduction is one of the most peculiar as it is one of the most fundamental characters of living organisms. And whilst the puzzling problem of sex and the extraordinarily complicated paths by which in some cases reproduction is ensured may captivate us, nothing is more remarkable than the fact of reproduction itself. To realise its full significance one must remember that so far as one knows to-day, living protoplasm and living organisms never originate from non-living matter. The old belief that worms and maggots arose from decaying flesh is easy to refute. To show that there is no *Spontaneous Generation,* as it is called, of bacteria and other microscopic simple organisms is more difficult. Since, however, the brilliant work of Pasteur and Tyndall, no one has been able to show that living organisms arise in any other way than from previously living organisms. Moreover, an organism only gives rise to its own kind. A germ of tuberculosis has just as certainly come from a previously existing germ of tuberculosis as a kitten has come from a cat. Now, this absence of spontaneous generation is a remarkable fact, for it leaves us absolutely in the dark as to the origin of life and living matter. There must have been a time in the dim, remote past when physical conditions on this earth were such that no possible form of life could have existed. Was this followed by one definite period when the conditions were so peculiarly balanced that living matter originated? If that were not the case, either living matter is arising to-day from non-living (without our being aware of it), or else at one time life reached this earth from some other heavenly body. Each idea has had its supporters.

The simplest and apparently the most primitive kind of reproduction is that found amongst the single-celled plants and animals. A bacterium, for example, during its life of about twenty minutes or half an hour incorporates new material into protoplasm and grows. A point is soon reached, beyond which further increase of size is impossible. (A very good reason put forward to account for this is that, with growth, volume increases as radius^3, but the surface area only as radius^2. We have seen that all the exchanges between the organism and its environment take place through this surface, which is thus gradually becoming too small.) The bacterium then simply divides into two, and the two smaller individuals commence to grow in their turn and live their twenty minutes of life. This is reproduction by *Simple Fission.* It need not be binary; many unicellular creatures divide into many parts—*Multiple Fission.*

One finds reproduction by simple fission in a great many lower organisms, whilst a variation of it is found in a few multicellular animals and quite a number of the highest plants. Thus a strawberry plant sends out " runners," and from the tips of these new strawberry plants grow. The runners then decay, leaving several plants which have arisen from one. Reproduction by cuttings is akin to this. Amongst animals the members of the group to which hydra, the jelly-fishes, and corals belong reproduce commonly by dividing. The same thing is normally true of many worms (and we can make it accidentally true in the common earthworm by cutting the animal in two); each half may then regenerate the lost part. Obviously this method of reproduction must be very limited in the higher animals, for one cannot conceive of a highly complex animal dividing into two parts.

Instead of this, the multicellular animals produce certain special cells, the germ cells. These are set free and from them, by repeated division, growth, and

differentiation, new individuals are produced. The parent animal eventually dies. The separation of certain cells from the body and their eventual growth into new individuals is not *in itself* very different from the separation of more complex parts, as when a worm divides into two or a rose-bush has a cutting removed from it. What *does* make it different is another phenomenon which is usually closely tied up with it—namely, sex. So much is this the case that we speak of all forms of simple fission, reproduction by cuttings, etc., as *Asexual Reproduction,* as contrasted with *Sexual Reproduction,* in which plants and animals produce special reproductive cells. Asexual reproduction only concerns one individual, and it does not matter whether it be male or female, or whether there be any distinction in sex in the animals or plants concerned, while almost always in sexual reproduction specialised parts of *two* individuals are involved. If we examine any species of frog by dissection, we shall find that there are individuals of two kinds (females and males), one of which possesses ovaries, which produce "eggs," whilst the other has comparable organs, the testes, which produce germ cells called spermatozoa. Had both types of germ cell been alike in structure, there would possibly have never been any distinction between the animals bearing them, and consequently no sexual differences. On the other hand, it is equally possible that without the existence of some sort of difference between the protoplasm of individual organisms (whether multicellular or single-celled) there would never have been what we call sexual reproduction.

Everyone has seen some sort of egg. Extremely few people have seen individual spermatozoa (although it is very easy to do so). The reason is that most eggs are big enough to be visible with the unaided eye. Spermatozoa are so small that they need a microscope to make them visible. They were seen in 1677, but it

was not until 1824 that it was definitely realised they were alone responsible for fertilisation; previously the fluid containing them had been accepted as a "fertiliser." Some animals produce both kinds of germ cells; they are called *Hermaphrodites* (the earthworm is one, the common garden snail is another). Under no conditions can a spermatozoon be made to grow up into a new individual, nor will the egg do so either unless certain conditions are fulfilled. Normally it is necessary that one egg and one spermatozoon should meet and fuse together. The product of their union is known as a fertilised egg and, given the right environment, it very soon commences that remarkable growth which leads to the production of the adult. The astonishing thing is that this sexual reproduction is well-nigh universal, and amongst plants as well as animals. There must be something very important in this curious complication of reproduction, for very little observation shows that it is a serious complication, and one that is not to be taken too much for granted. Why should there be *two* kinds of germ cells? Why should there be sex? Why should *two* germ cells have to make a complete union in order that a new individual should arise? These are the fundamental points in the puzzle of sex.

The case rests as follows. Reproduction is a universal feature of living organisms; without it life would come to an end. There are various types of successful asexual reproduction, but the sexual method is almost always present in addition. Yet compared with asexual reproduction it is not economical. One has only to glance at the animal world to see this, for sexual reproduction practically always means two parents. A male and a female plaice or herring must be in proximity to each other at the breeding season. Each sheds its germ cells into the sea. Millions of spermatozoa must be produced to provide any certainty of the eggs being fertilised. Indeed, all the romance of

sex amongst plants and animals, and it is a romance, is interwoven in Nature's efforts to bring about the union of these germ cells. Why such wasteful methods when asexual reproduction can be successful?

When a sperm cell meets an egg and fuses with it, the nucleus of the sperm cell passes right inside the egg and still moves on until it meets the nucleus of the egg. The two then fuse and make one. Shortly afterwards the fertilised egg begins its development. Experiments have shown that we can distinguish two quite separate actions in this fertilisation union. All the world was startled when, in 1906, Loeb, an American scientist, showed that it was possible to make eggs develop without the presence of sperm cells at all. The stimulus which replaced that of the sperm cell was chemical. Starfish eggs can be made to develop by placing them for a short time in sea water which is a little more concentrated than normal, or has various other elements added to it.

Other stimuli have been discovered which may set an unfertilised egg developing; frogs' eggs, for example, can be made to do so by pricking them with a fine needle in the presence of a little blood. Here, then, is our first clue. Since the stimulus to development need not necessarily be fusion with another cell, we may deduce that the egg cell contains within itself the complete mechanism for the formation of a new creature. Other experiments have shown that as a result of normal fertilisation the sperm cell and the egg can, notwithstanding their different sizes, contribute equal shares in the characteristics of the offspring. Children may inherit as much from the father as from the mother. These observations provide our second clue, and, putting the facts together, it is legitimate to conclude that in fertilisation the sperm cell provides (1) the stimulus to further development, and (2) hands over in its nucleus a material bequest of hereditary characters. Now, since we can easily replace

the stimulus to development artificially, and since in Nature there are many cases where eggs do develop without fertilisation (certain eggs of the honey bee, the green aphids, etc.), we may go a step further and say that it is the second result of egg and sperm union that is really important—*i.e.,* the mixing of living substance from two different organisms, the mixing of two sets of hereditary characters. It is difficult to see how this could be achieved in either plants or animals, except at the comparatively simple stage when they are represented by the germ cells. Sexual reproduction provides, therefore, the mechanism for a mixing of living substance of at least two different cells, generally from two different individuals.

(It is unfortunate that the term "fertilising" is used so often in everyday life for the application of chemicals to vegetable growth to stimulate it and provide food. It tends to exaggerate the importance of the egg cell in animal reproduction, and to stress the action of the male cell as that of a stimulant to further development. It must be kept in mind that this stimulating action is secondary to that of the mingling of two sets of characters.)

Why should sexual reproduction have brought with it males and females, which are often very different in appearance? It is not difficult to suggest an explanation. The germ cells are very frequently shed and left to develop further. Some material for the construction of the new individual must be supplied until it is capable of absorbing food itself. At the same time it is essential that the germ cells should have some power of movement, even if slight, to facilitate their union. Nature has again specialised; the cell which we call the egg stores the food material and has no power of movement; the spermatozoon lacks all food store, and is very small, but it is active. This difference in the germ cells is obviously going to be reflected at least in the internal structure of the animals producing them.

If that were all, the only difference between males and females might be internal. Such is actually the case in many animals, especially those which are aquatic and shed their germ cells into the sea, where their union is somewhat a matter of chance. But it is no use shedding delicate germ cells on land, and sperm cells are, of course, adapted for motion in a fluid medium. Thus, with the advent of life on land and in the air, other mechanisms had to come into existence for bringing sperm cells into the immediate neighbourhood of egg cells. This not only led to big differences in structure between males and females, but to differences in habits, and to a vast diversity of devices for making reproduction more certain and less wasteful. Even amongst aquatic animals we meet the same thing. Finally, we find arrangements for the protection of the eggs *after* fertilisation and whilst undergoing their early development. To this end they may either be nursed and guarded by the parents or kept within the body. The culmination of the process is seen in the highest animals, the mammals, where the eggs are not only fertilised within the body of the mother, but kept there until a very high state of development is reached, when birth takes place. In brief, sperm cells are practically always passed out of the animal producing them; eggs may be shed or may be retained for a shorter or longer period during development.

It is interesting to see how certainty of fertilisation and safety during development is reflected in the number of germ cells produced. Aquatic animals, which simply shed their eggs and sperm cells into the water, produce incredible numbers—a female turbot, 9,000,000 eggs per annum; the codfish, 6,000,000 eggs. Heaven only knows what the number of the spermatozoa must be in these cases. (It has been calculated that in man there are approximately 850,000,000 for each egg produced in the life of the female!) The eggs of the dogfish are fertilised within the body of

the female, and are laid enclosed in a protective shell; the female dogfish only produces a few eggs in a year.

The female housefly lays its eggs on refuse in batches of a hundred or more at a time, and five such batches in its summer life. On the other hand, the African tsetse fly, notorious for its transmission of the parasites causing sleeping sickness, retains its fertilised eggs within its body until they have developed beyond the early stages; it produces only one young at a time. Certainty of fertilisation (usually only ensured by the male inserting the sperm cells directly into the female) and parental care of the young save the enormous wastage which otherwise occurs.

It is not remarkable that the conger eel and probably a high percentage of salmon never survive their single breeding period; the marvel is that so many animals do survive. No one who studies reproduction can fail to see the heavy price paid for the continuance of the species. Nor can one miss the driving force in the instincts behind it. All the romance and all the tragedies of human history whose causes lay in the loves of man and woman are reflections of that urge to safeguard the race which is traceable from the simplest creatures upwards.

In some animals periods of asexual reproduction alternate with sexual reproduction. For example, the common freshwater hydra, during the summer, throws out small "buds" on its sides, and these become detached as independent individuals; it is a form of simple fission. In autumn, eggs and sperm cells are produced, and the eggs, after fertilisation and a brief period of development, rest as a resistant stage through the winter until a more favourable season returns. Numerous cases may be found where, during seasons when food is plentiful and all the conditions are favourable, reproduction takes place asexually (and hence without the waste and delays which seem so often associated with the sexual method). The green

fly, that wretched plant pest which torments lovers of rose-gardens, provides another example of this; but it is not quite correct to call it alternation of asexual and sexual reproduction. With warm air and favourable conditions successive generations of females are found. Each insect lays eggs *which develop without fertilisation,* and all turn into females. Males are dispensed with. It is easy to see how enormous numbers appear in a short time. But after a comparatively long period arrangements are made for the intermingling of protoplasms, and before winter comes males as well as females are produced. The females of this generation lay eggs which *do* require fertilisation.

The phenomenon of the development of eggs without fertilisation at all is called *Parthenogenesis.* In one or two cases in the animal world it has reached such a point that males have become non-existent. Fertilisation is unknown; all the individuals are females.

The honey bee presents us with parthenogenesis under another aspect. The queen bee—*i.e.,* the fertile female, is impregnated with spermatozoa by a Drone (a male). After this she can go on laying eggs for a year or two, and can control their fertilisation. If an egg is fertilised before it is laid, it becomes a female; if it is not fertilised, it develops all the same (parthenogenetically), but becomes a male.

Parthenogenesis reminds us again of the discovery that some eggs can be made to develop by artificial means. It is further confirmation of the idea that the fertilisiation union of germ cells is primarily something other than reproduction, although the two things have become associated so very, very closely.

In seaweeds, mosses, and ferns sexual reproduction is very like that seen amongst animals. In fact, the easiest way to demonstrate to students the fertilisation of an egg cell by sperm cells is to experiment with the common, brown seaweed of our coasts. Amongst plants, however, one frequently meets with what is

called *Alternation of Generations*. The common bracken fern produces tiny bodies, the spores, on the underside of its fronds. These fall on the damp soil and develop into little green plants called prothalli, about a quarter square inch in area, and quite unlike fern plants. This is asexual reproduction. It is on these prothalli that the organs containing germ cells analogous to eggs and sperm cells are produced, and then fertilisation leads once again to the bracken fern stage.

This alternation of asexual and sexual reproduction is found right up to the so familiar flowering plants, but, unfortunately, it is not so easily demonstrated. The fern prothallus is very small indeed when compared with the bracken fern stage. In the higher plants this sexual stage becomes smaller and smaller until finally it ceases altogether to have an independent existence, and one must look for it on the asexual plant. The pollen grains (so often wrongly compared to animal spermatozoa) are, in reality, the spores from which develop the most minute male sexual stages; the ovules (often compared with animal eggs) are really sporangia. Pollination of flowers—*i.e.*, the carriage of pollen from one flower to the central part, the stigma, of another, is consequently not at all comparable with a sperm cell being brought into contact with an egg.

Growth is so characteristic of all living things that it is often taken very much for granted. It is not mere increase in size, although that would in itself be interesting, for it implies the conversion of non-living substance into protoplasm. The term as used in biology covers some extraordinary phenomena, including processes which have been utilised more than once in the conflict between the mechanists and vitalists. An amœba may grow by a simple increase in size; a multicellular animal developing from an egg increases in size, but at the same time it becomes different in shape and appearance, and its parts gradually become

materially different in constitution. Let us commence with the fertilised egg of a frog. It initiates its development by dividing, and, divisions continuing, a large number of smaller cells result. Then the cells (all of which are simple and undifferentiated, like the egg cell which gave rise to them) begin to arrange themselves in this way and that way. Cell division continues, here faster, there slower, until by division, by folding, by rapid growth here and slow growth there, a definite form is gradually moulded and the foundations of different organs are laid down. But what are the forces which control this moulding, and where are they situated? At first one was tempted to suppose that the fertilised egg contained factors for the growth of the complete organism, and that at each division these factors were shared out. The case turns out to be different. Experiment shows that normally the first division of the frog's egg gives two cells, each of which will be the progenitor of all the cells of one half of the body. If, however, these two first cells are carefully separated (without injuring them), each goes on dividing, and two complete individuals result. Clearly there has been no sharing out of factors. All the evidence tends to show that the moulding of the developing embryo is, in some way, dependent upon the proximity and interaction of the cells of which it consists, but a controlling mechanism at this stage is hidden.

As events proceed further a little more information can be gained. For example, at one period an outgrowth of cells from what is clearly the fundament of part of the brain appears exactly opposite an ingrowth of cells from the outer surface of the embryo. Events show that these two growths will combine to form an eye, one becoming the lens, the other the retina. By extremely delicate manipulation it has been possible to remove one or other of these growths, and as a result it has been demonstrated that the ingrowth of

the outer layer to form a lens is a response to the presence of the retinal outgrowth of the inner layer. Indeed, it is possible to make an altogether different region of the outer layer of embryo grow inwards to form a lens by transplanting the retinal outgrowth underneath it. This is the kind of experiment which is being made to find out why a tiny "blackberry-like" mass of cells should divide and redivide, with a spontaneous marshalling of the resultant cells hither and thither into layers and folds and tubes, until out of it all a tiny embryo results.

Let us assume that the organs of the adult have now been mapped out; their cells are still embryonic and undifferentiated. From this point growth includes increase in size, multiplication of cells, and *Differentiation,* which means that the cells become specialised and unlike in form and structure. Regulation is continuously manifested, and each part (if conditions are normal), just balances its neighbouring parts. Eventually, after some vicissitudes, the adult stage is reached, and growth phenomena slow down or come to a standstill altogether. Finally, even cell life appears subjected to some "braking" process; a condition of senescence replaces that of activity, and ultimately death occurs. It is only natural, especially after a study of the "immortal" protozoa, to ask why growth ceased, and what prevented the continued existence of the animal.

The power of growth, as expressed by cell division, seems to disappear as cells become differentiated or specialised in structure and function. But the power of growth is not always lost when an animal is grown up and its tissues differentiated. Hair on a mammal continues to grow even in old age; cuts in the skin heal up. A lizard has often escaped me in the Australian Bush, because in an excited chase I have gone eagerly after what turned out to be its thrown-off tail. A new tail with muscles and other tissues is grown by the

animal. On the whole, however, tissues do not grow after they have differentiated. This is quite in accordance with the lizard's tail example, because if examination be made of the growing stump it will be found that the tissues of the new tail are not growing direct from tissues of the stump, but from a mass of undifferentiated cells which have appeared from somewhere. Possibly a few cells, retaining their embryonic non-specificity, were lurking amidst the tissues at the base of the tail before it was broken. It is not impossible, however, that some differentiated cells " went back on their tracks," so to speak, and dedifferentiated. This rather startling conversion can actually be produced; it is also found in malignant tumours. With dedifferentiation the power of growth and cell division returns, and unfortunately, in the case of malignant tumours, the uncontrolled growth continues. There seems no limit to the life of such cells, and a tumour can be transplanted through generations of mice without coming to an end.

Much light has been thrown on the subject recently by experiments in the culture (in little glass dishes) of tissues taken from living organisms. Arising out of the successful culture in nutrient media of all sorts of bacteria (a commonplace to-day of bacteriological laboratories) the culture of animal tissues has turned out to be far more interesting than was anticipated. Cells which have ceased to grow in the animal from which they have been taken, may start afresh when isolated in the culture media. Specialised tissue may be seen to dedifferentiate into non-specialised—*i.e.*, embryonic, cells again and the power of growth is regained. After generations and generations of such embryonic cells the introduction of a piece of normal tissue into the culture may cause differentiation once more.

Everything indicates that growth is characteristic of living protoplasm, and that where this is not taking

place some repressing factor is present. Such repressing factors come into play as any animal's body is normally developed. On the other side, certain substances appear necessary in order that growth may take place, and there are other substances which appear to "speed up" growth and protoplasmic activity in general. Vitamin D has already been referred to in this respect, and mention has been made of the secretions of the ductless glands in the bodies of vertebrates. Cretins are the result of deficient development of the thyroid gland, and in many cases a dwarfed, ugly, imbecile, cretinous child has been changed into a normal creature by feeding with thyroid gland taken from other animals.

The well-known galls and other abnormal outgrowths on plants are due to a growth stimulus exercised by substances injected by insects, or by substances given off by insect parasites. In the case of malignant growths it is not necessary for the initiating stimulus to be continued; active cell growth once re-established seems to go on automatically.

No one has yet satisfactorily explained senescence in the multicellular animal, except in so far as specialisation and differentiation mean loss of growth power. Since protoplasmic life implies wear and tear and replacement, any difficulty in performing the latter is bound to result in death sooner or later. Probably no human beings have ever died as the result of uniform and natural senescence of the tissues of the body. Something happens to one or other organ before such a condition is reached. Accidents happen, bad environments and bad habits all conspire to upset the equilibrium of the organs in our big but restricted cell community, and when natural senescence is only just beginning, temporary low conditions may enable disease germs to find a lodgment where once the body might successfully have dealt with the invaders.

Whether natural senescence can be postponed is

another question for the future. Remarkable results have recently been claimed for rejuvenation, following the transplantation into man of the testicular glands of other animals. The future will show whether this is merely a reawakening of sexual instinct or a true rejuvenescence.

CHAPTER VII

ORGANIC EVOLUTION, HEREDITY, AND SEX

One can safely assert that no theory in science has been the source of more public discussion than that of *Organic Evolution*. No doubt this is due to the fact that the theories of astronomers, geologists, and other scientific workers have never touched popular religious beliefs so closely. The result might well be expected—no theory in science has been so mutilated and so misconceived as that of organic evolution. Even to-day popular writers frequently assume that the theory of evolution is the same thing as Darwin's theory of Natural Selection, and thus when they hear that Darwin's theory is the subject of discussion and criticism by scientists they jump to the erroneous conclusion that the great concept of evolution is the subject of the attack.

The idea of organic evolution is no novelty of the past century. From the time of the great Greek civilisation the idea has slowly gained ground that animal and plant life has gradually unfolded itself, branching out into all the varied forms existing to-day (and including all those which have become extinct in past ages). With the ever increasing mass

of anatomical knowledge, it began to assume much more definite form in the period (1700-1800) before Charles Darwin's birth, until ultimately a very definite theory of evolution was propounded by Lamarck in 1809, the same year that Charles Darwin was born.

The way had not been paved for the acceptance of such a theory, and certainly before Lamarck's time most theories had been exceedingly speculative. During the short period between Lamarck and Darwin the " atmosphere " changed somewhat, and the publication of Lyell's principles of geology in 1832 created an altogether new situation.

Charles Darwin, after having spent twenty-two years in accumulating and setting out his facts, produced an overwhelming volume of evidence for evolution, and, in addition, furnished an ingenious theory for the *modus operandi* of the evolutionary process. His theory was first published in book form in that classic, *The Origin of Species,* in 1859. The first public exposition was in the previous year at a meeting of the Linnean Society in London, and at the same meeting a paper was read by Alfred Russell Wallace who, by one of those extraordinary coincidences, had come to practically the same conclusions as Darwin in regard to evolution by Natural Selection.

Since Darwin's time all thinking people have come to accept evolution as the only logical way in which the living world can be interpreted and understood. One might affirm that the concept of evolution made biology a science. Apart, however, from the importance of evolution on the theoretical side, there is a practical issue. The study of evolution is linked with the study of heredity, and both enter into modern investigations in medicine and in animal and plant breeding.

Many discoveries of science are accepted with keenness by the everyday world when they become

of commercial value; others just as remarkable are ignored because they have not yet any "cash value." The evolutionary theory occupies a different place; it attracted popular attention because it conflicted with a belief in "Special Creation." But one might point out that Special Creation is *only one way* of interpreting the first chapter of Genesis, and that one the least thoughtful and least inspiring. It is just as well to regard the description in Genesis as "a simple story beautifully told, derived from Hebrew tradition and well suited to the state of knowledge of the times and of the people for whom it was written" (Lull).

If the concept of evolution stands firm to-day, it is quite a different matter in regard to the explanatory theories. Obviously there could be no evolution if there had been absolute identity between parents and offspring. Now it is well known that differences (large and small) between parents and offspring, brothers and sisters, exist everywhere in the animal and plant worlds. These differences (or more accurately, perhaps, the degrees of difference) are known as *Variations*. They are the material basis of evolution, and if we had a complete understanding of the forces which controlled them, we should probably have a complete explanation of the evolutionary process.

The subject is now so vast that we cannot attempt to say more here, and in any case it would be needless duplication, for books on Evolution and Heredity are appearing in the present series. We shall have served our purpose if we indicate that the study of the *modus operandi* of Evolution is still in the foreground of biological research, and that whilst Darwin's theory of Natural Selection is very strongly held to-day, there are many biologists who will only accept it as one of the ways in which evolution may have progressed.

The study of *Heredity,* which is so closely intertwined with evolution, has brought to light such remarkable discoveries that once again we have to refer the reader to another treatise for detailed information. Originally, research in heredity was entirely a matter of observing the results of breeding. A new aspect was introduced when Mendel's discoveries of certain laws were made known in 1900. It is now actually possible to prophesy fairly exactly what will happen when certain animals or plants are crossed.

Modern investigators have carried the matter much further than this, and it has been possible to show (by means of the microscope and with the aid of elaborate staining technique) an actual structural mechanism in the cell nucleus which is concerned in heredity. The microscopic study of the germ cells now goes hand in hand with breeding experiments, the results of the former explaining those of the latter. Out of the vast assemblage of results, one picked at random will serve to illustrate the type of some modern work.

The human disease hæmophilia is marked by an inability of the blood to clot when a bloodvessel is cut and the blood escapes (obviously a dangerous character, for clotting is a natural way of preventing loss of blood). It only occurs as an inherited character and *is only present in males,* although evidence shows that it is inherited from the mother who herself shows no signs of hæmophilia.

Exactly the same type of inheritance is found in a small fruit fly, where white-eyed flies appear in the progeny of certain crosses between red-eyed flies, and all these white-eyed flies are males. We can perform all sorts of breeding experiments with these flies, and we can with little difficulty bring to light the microscopic structure of their germ cells. Such research shows that a factor for white-eye colour has been

carried in the nuclei of the cells of the red-eyed mother and is present in all her eggs. What happens in the succeeding generation depends upon the nuclear constitution of the sperm cells which fertilise these eggs. There can be no reasonable doubt (from the results of other investigations) that exactly the same type of mechanism explains hæmophilia in man, which is inherited in a similar manner.

This example leads naturally to another question of paramount interest in biology at present, the phenomenon of *Sex*. What determines whether a fertilised egg will grow into a male or a female? The investigation of this problem is receiving great attention, not only because the problem in itself is interesting, nor because knowledge of the factors might enable us to control sex, but because events are indicating that this line of investigation will provide another method for elucidating the mechanism of heredity and possibly some of the deeper phenomena of life itself. At present we know that in the majority of cases sex is determined (fixed) at and by the union of egg and sperm cell when the former is fertilised. Apparently both the egg and sperm carry factors for sex just as they carry factors for other characters which are inherited. But the matter is not quite so simple as this, because many examples are known where the sex of an individual has changed during its life. (Poultry farmers are now quite familiar with hens which, owing to ovarian disease, take on the plumage and even other sex characters of the cock.)

From such examples we might conclude that probably all fertilised eggs possess factors for the inheritance of all the characters possessed by either sex, and that which set actually develops is a matter of the interaction of certain other factors brought together at fertilisation, an interaction which, quite conceivably, might be influenced later by the environment (using the term in the widest sense).

CONCLUSION

THE MODERN TREND OF BIOLOGY

WE have endeavoured in the preceding pages to indicate the kind of problems which the biologist is facing to-day and some of the fundamentals upon which these problems rest. There are many branches of biology and all serious workers are specialists. It is not difficult, however, to distinguish one particular " surge " in which discoveries in every line of research play a part. It is the effort to explain life itself. The living cell is to the biologist what the molecule has been to the chemist. Can the living cell be completely explained by physico-chemical theories of the same order as those which have led to so much progress in the past?

There have been many battles between so-called mechanists and vitalists; and the vitalists and neo-vitalists, with mysterious vital forces, an *élan vital* (Bergson) or an *entelechy* (Driesch), do not seem to have emerged very happily from their conflicts. The mechanists, on the other hand, are perhaps unduly confident, although one must admit the wonderful results of the application of mechanistic principles. To-day, however, there is a changed atmosphere in science, and when a professor of mathematics can write: " Time, space, matter, material, ether, electricity, mechanism, organism, configuration, structure, pattern, function, all require reinterpretation. What is the sense of talking about a mechanical explanation when you do not know what you mean by mechanics?" it would appear that biologists, too, may have to look towards a new philosophy.

Meanwhile, the discoveries in heredity have reached a stage of great practical importance, with an ever increasing possibility of human application. Laws

will probably have to be modified, and much social change may result. Our increased knowledge of the factors which are necessary for life (including the recent developments in regard to vitamins, ductless glands, tissue culture, sunlight, etc.) are being crystallised into a great effort for the prevention of human disease. We are only beginning now to apply a little of the knowledge already gained. The entomologist is pushing home his attack against insect pests, the fisheries expert is watchful of the productivity of the seas, the application of botanical investigation is a necessity in successful agriculture. No animal or plant is or can be excluded from investigation, and one never knows where or when an observation will be made which will open up a new avenue of inquiry.

> "A hair perhaps divides the False and True;
> Yes; and a single Alif were the clue—
> Could you but find it—to the Treasure-house,
> And peradventure to The Master too."
>
> *Omar Khayyám.*

One scarcely dare prophesy the possible results. The past fifty years have seen amazing changes consequent on the discoveries of chemistry and physics and our resultant control of machines. Biology will work far greater changes than these, as its discoveries bring the possibility of controlling the living organism. One can only hope that man himself will advance, and be better fitted ethically to take command of the powers now granted him.

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